UAVSAR: An Airborne Window on Earth Surface Deformation

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Von Karman Lecture Series

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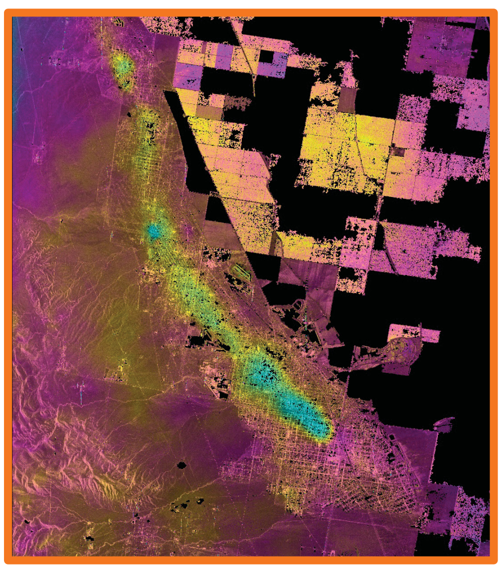
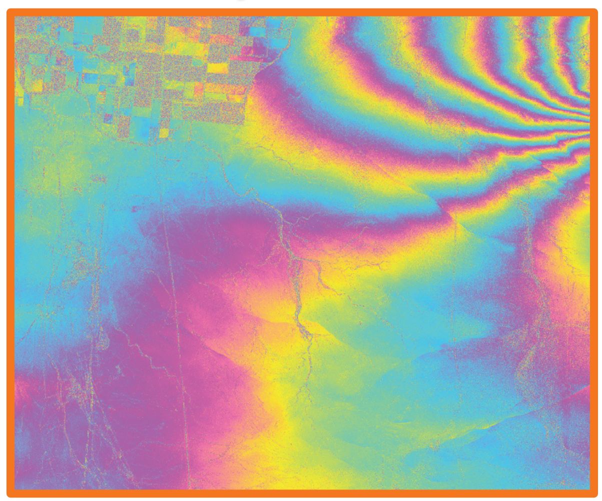
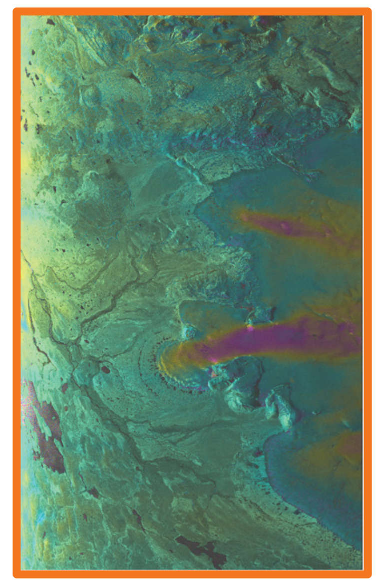






Acknowledgements

- This talk would not be possible without the work of many individuals who worked on the design and building of UAVSAR, process the data, and who use the data for scientific analysis.

- Special thanks go to:
  - NASA's Earth Science Technology Office for sponsoring the development of UAVSAR.
  - UAVSAR Team – For the collection and processing of most of the imagery shown in this presentation.
  - Eric Fielding (JPL) –Baja Earth Quake Slides
  - Paul Lundgren – Lander's Interferogram
  - Brent Minchew/Mark Simons (Caltech) – Iceland Interferograms
  - Jerry Treiman (California Geological Survey) – Baja Earthquake Slides

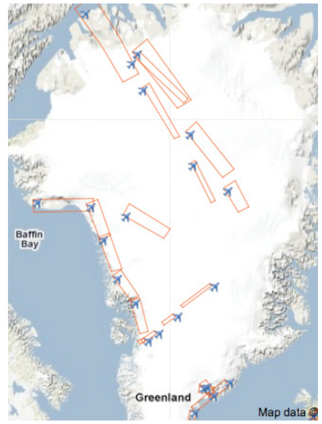
Origins of UAVSAR

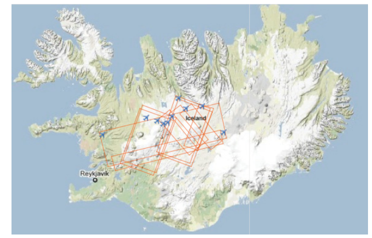
- UAVSAR is a NASA/JPL radar whose primary design goal is to enable robust measurements of deforming surfaces either from natural or anthropogenic causes.
- UAVSAR began as an part of NASA's Instrument Incubator Program, a program designed to support the development of new instruments for Earth or planetary observation.
  - Proposed science capability was highly desired, however NASA wished to have the capability supported on multiple platforms including uninhabited aerial vehicles (UAVs).
  - Developed a pod mounted radar having the desired measurement capability from 2004-2008.
- UAVSAR began routinely collecting data for scientific investigations starting 2008.

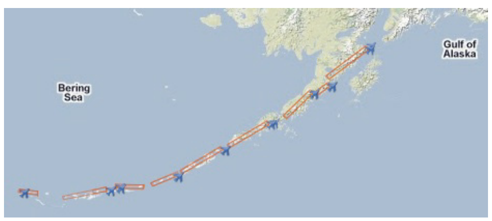
First UAVSAR Image
Rosamond Lake Bed
September 2007

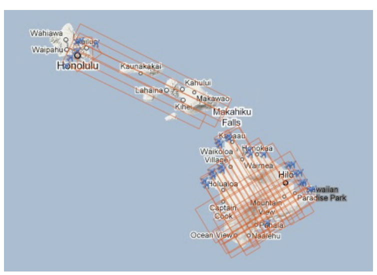
UAVSAR Missions

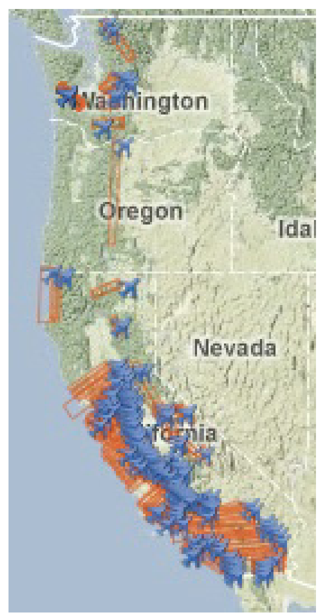
- UAVSAR has made observations spanning locations from Iceland to Hawaii.



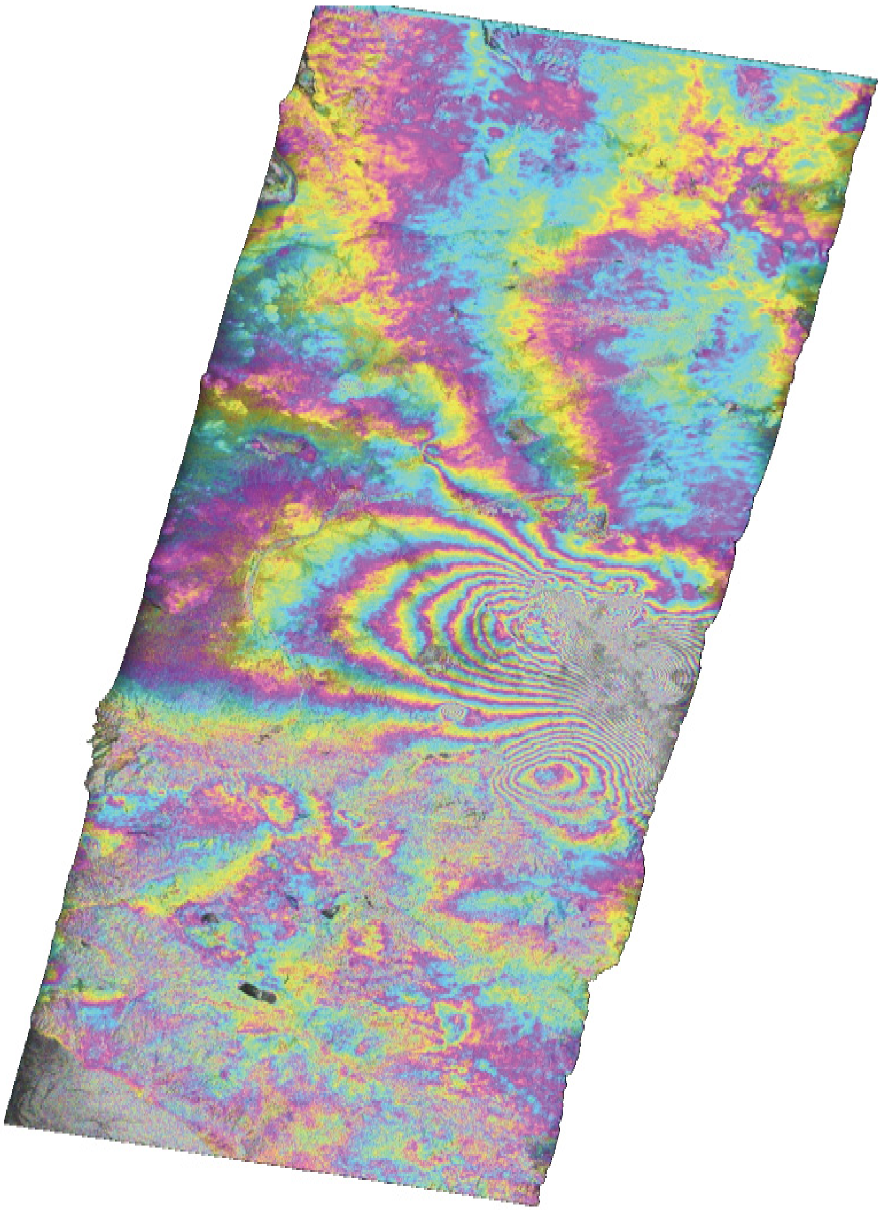








Seeing an Earthquake!



- In 1993 Massonnet* et al, published a **satellite** radar image showing deformation of the earth from an earthquake.
- For the first time it was possible to see the deformation associated with an earthquake over a wide area with fine resolution.
- Since then radar imaging techniques have become a ubiquitous means of analyzing surface deformation.

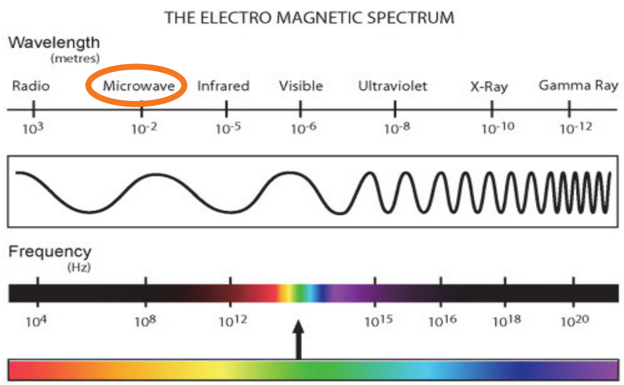
UAVSAR transitions this capability from satellites to airborne platforms.

*Massonnet, et al, *The displacement field of the Landers earthquake mapped by radar interferometry,* Nature 364, 138 - 142 (08 July 1993)

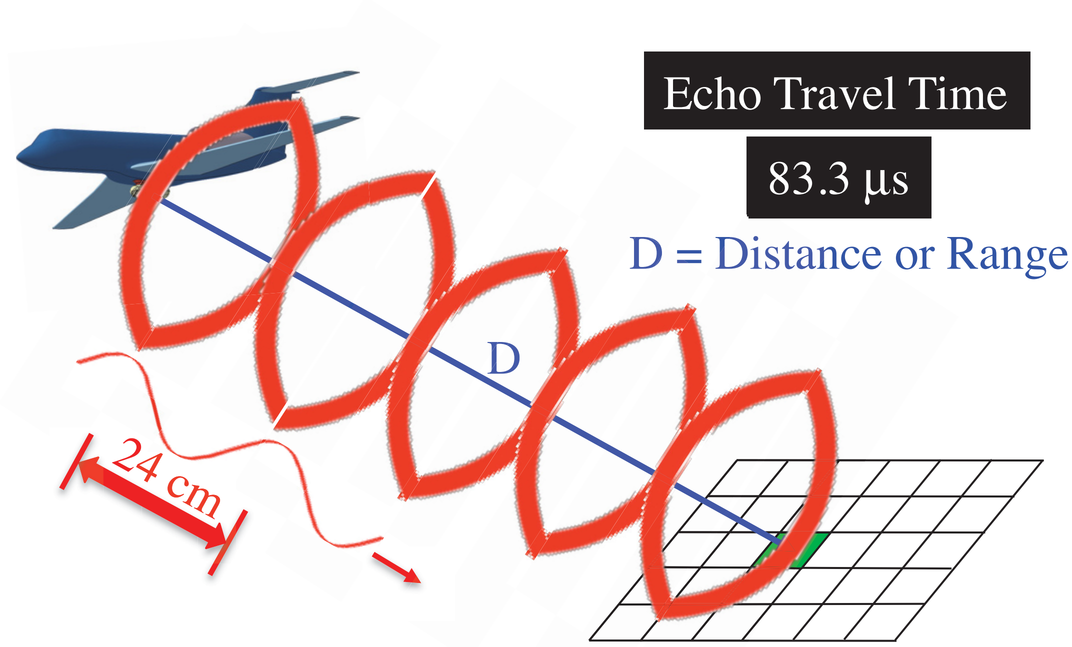
Radar Imaging

- Normally, technology is transitioned from airborne platforms to satellites instead of the reverse path of UAVSAR. Why was that?
- To answer that question we need to know just a little about radars.

Radar = Radio Detection and Ranging



Radars emit microwaves, a form of light with wavelengths about 100000 times longer than visible light, and measure the reflected signal.

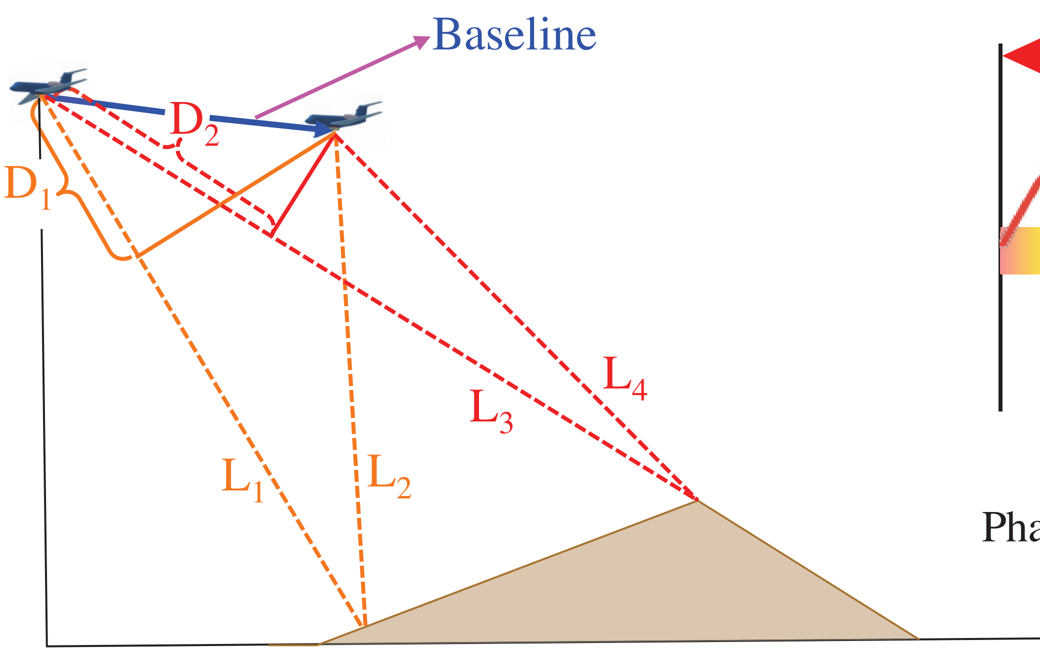


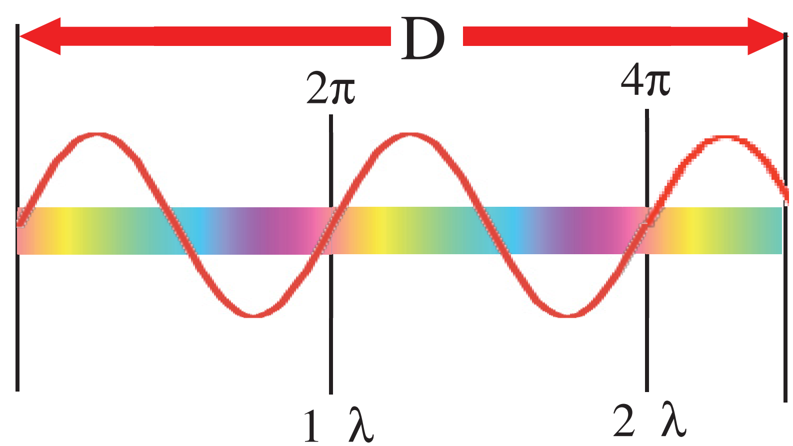
Reflected Signal at an Image Pixel: Strength of reflected signal & "phase" - encodes sub-wavelength range information

Distance determined from round-trip time it takes microwaves to travel from antenna to object

Radar Interferometry

- Measuring surface deformation from radar imagery uses a technique called radar interferometry that combines information from two radar images.
- Interferometry uses the sub-wavelength range information encoded in the PHASE of the reflected signal to measure **DIFFERENTIAL** range to a pixel in the two radar images.





$$\text{Phase} = \underbrace{2\pi}_{\text{Radians per wavelength}} \underbrace{\frac{D}{\lambda}}_{\text{Number of wavelengths}}$$

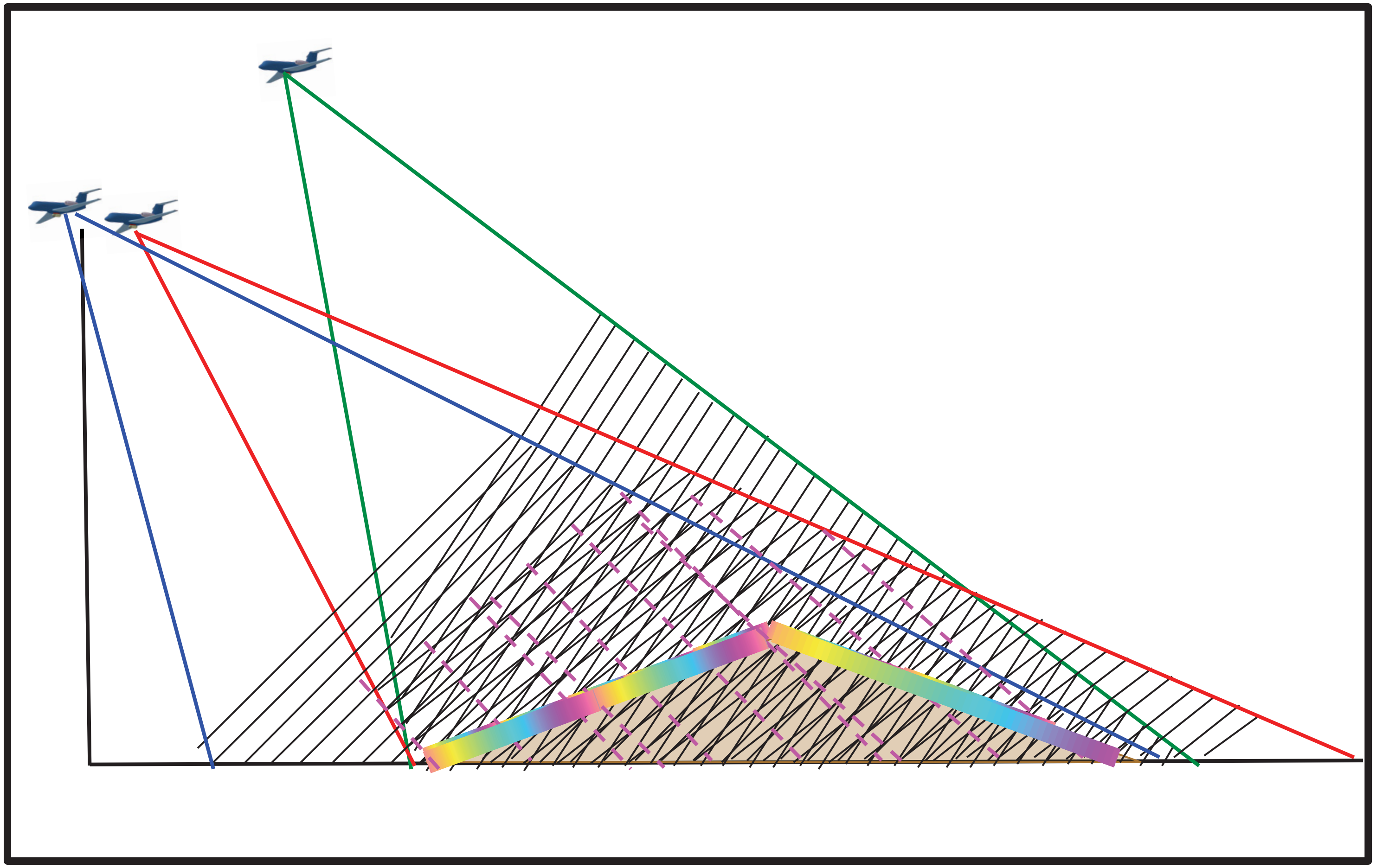
Differential Ranges

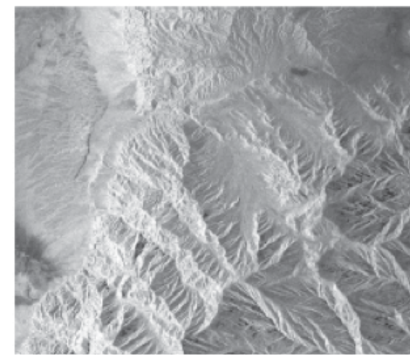
$D_1 = L_2 - L_1$ $\qquad$ $D_2 = L_4 - L_3$

Differential range can be measured with sub-wavelength precision, that is millimeters, using the phase information!

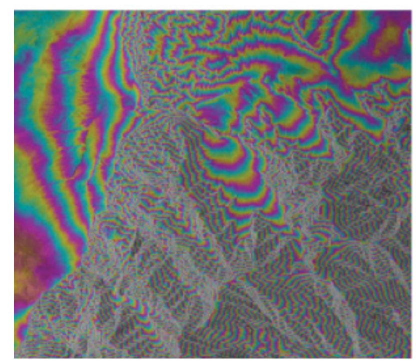
Interferometric Phase and Topography

- If the baseline is non-zero the interferometric phase contains topographic information than can be used to generate topographic maps.
  - When mapping surface deformation this part of the phase is undesired.



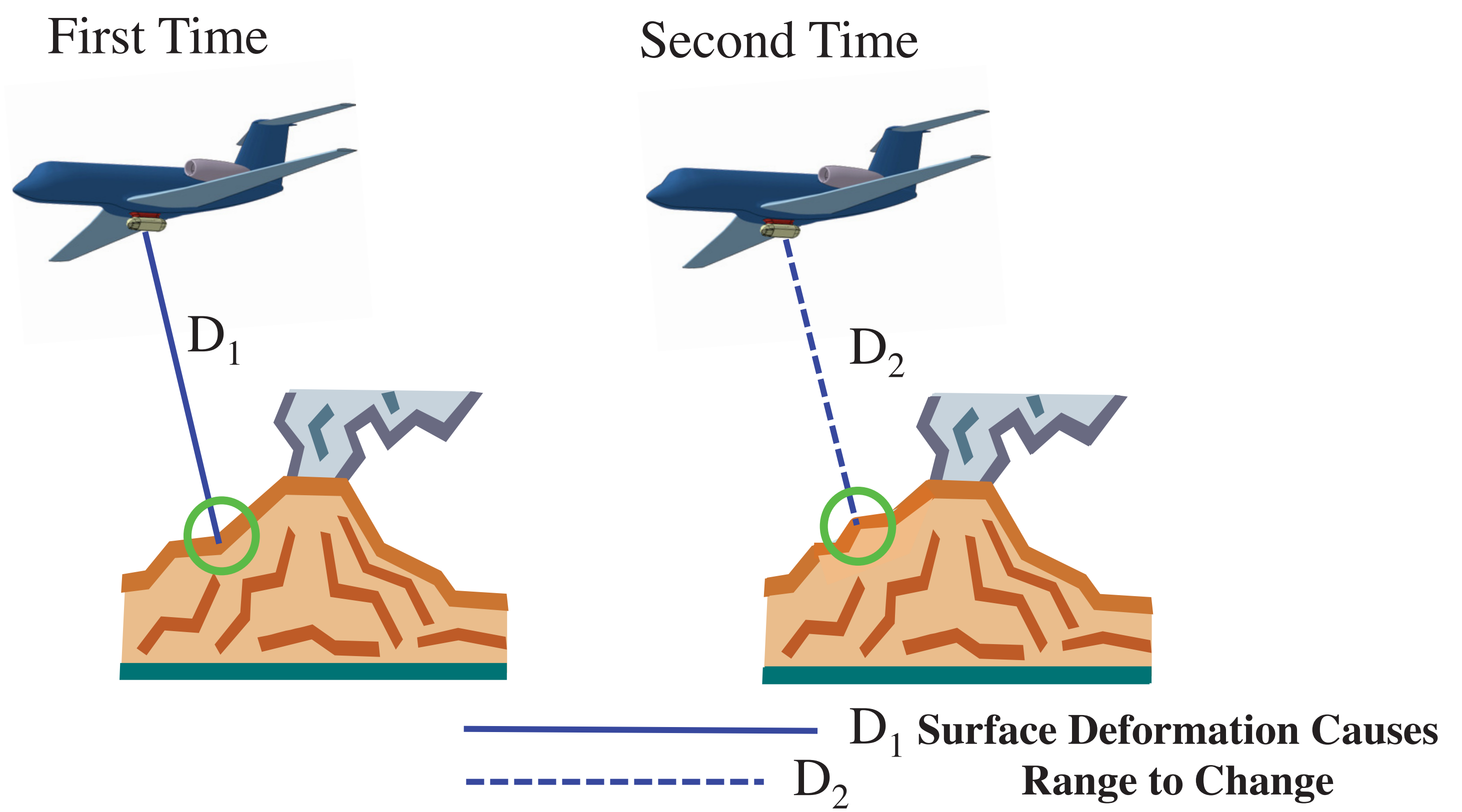


Reflected Signal Magnitude



Interferometric Phase

Radar Interferometry and Surface Deformation



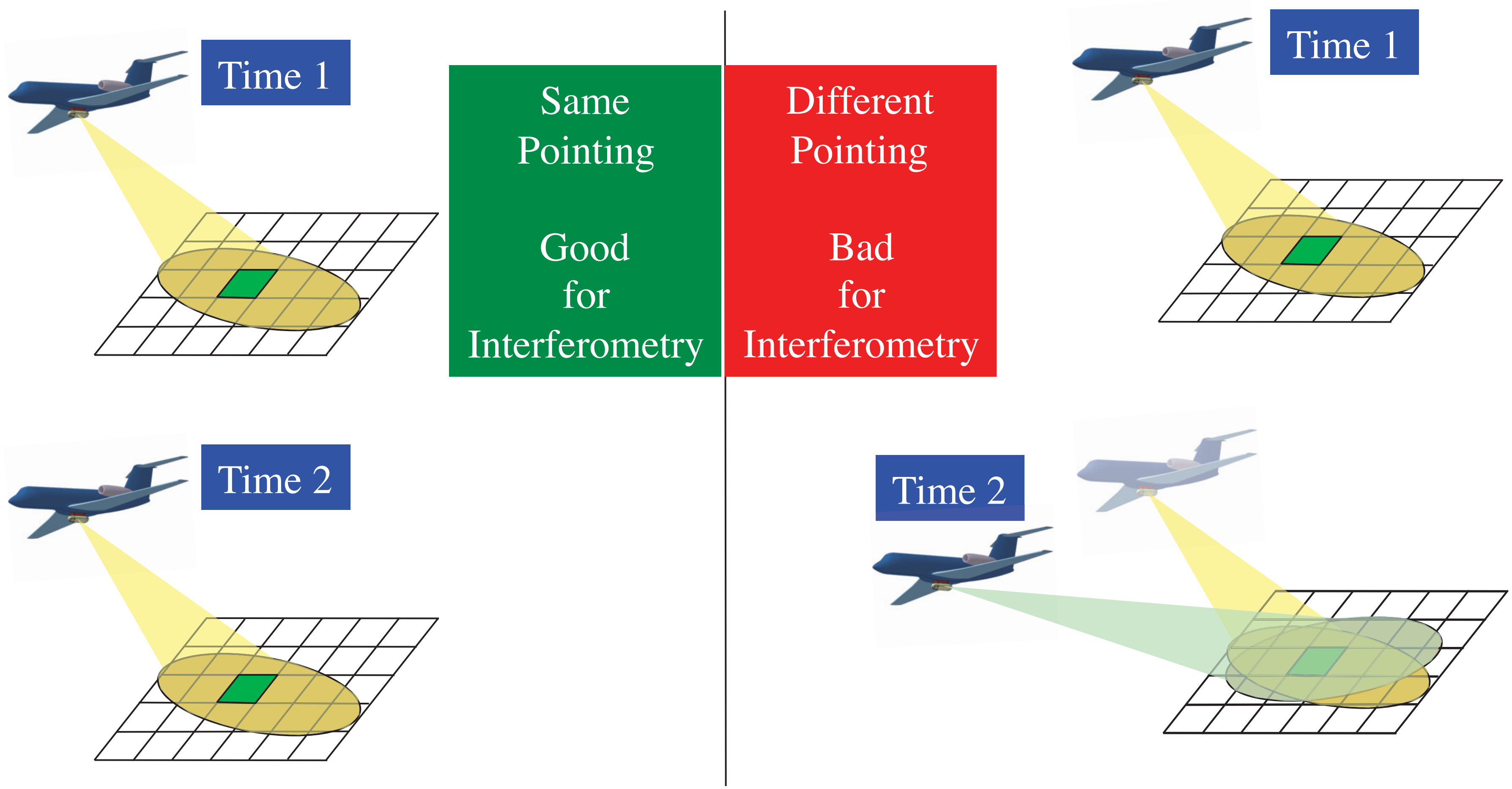
Surface deformation is reflected in the change in distance to a point.

$$\boxed{\text{Surface Deformation} = D_2 - D_1}$$

$$\text{Phase} = \underbrace{\text{Surface Deformation}}_{\text{Desired Signal}} + \underbrace{\text{“Topography”}}_{\substack{\text{Small baseline facilitates} \\ \text{compensation of this term}}}$$

One more thing about interferometry…

- To make deformation measurements the radar must be pointing in the same direction to a fraction of a beamwidth on the two passes.
  - This is challenging on a aircraft because of variable wind conditions between data collections.



Measuring Surface Deformation Robustly

- To map surface deformation robustly on an airborne platform requires two basic ingredients:
  – Be able to fly very close to a desired path (within a few meters) to maintain a small baseline between passes.
  – Have some means to adjust the antenna pointing so that it remains the same between passes.

- The much increased irregularity of aircraft flight paths compared to satellite flight paths (no wind to push them around) is what makes deformation mapping with radar more difficult on an aircraft.

- Since it works on a satellite why have an airborne capability?
  – Satellite revisit times vary from 11 to 46 days which is longer than desired for some applications.
  – Satellite imaging geometries do not have the flexibility of an aircraft.
  – Finer spatial resolution is possible than with most radar satellites.

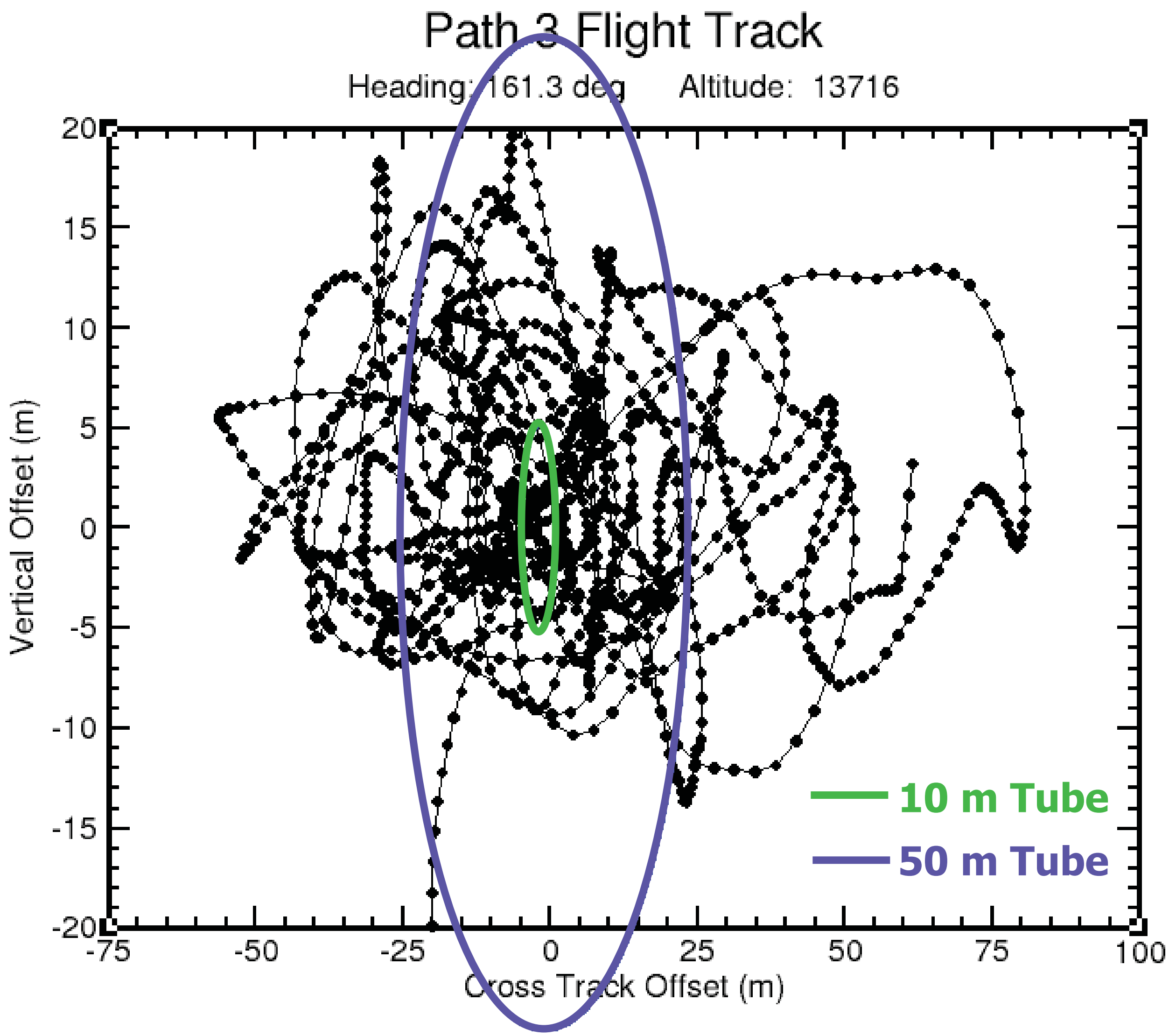
UAVSAR – Flying on a Gulfstream III

- UAVSAR is an radar that has been designed to support a wide range of science investigations. The UAVSAR design incorporates:
    - A precision autopilot developed by NASA Dryden that allows the platform to fly repeat trajectories that are mostly within a 5 m tube.
    - An antenna that automatically adjusts in pointing electronically to maintain a desired pointing direction.

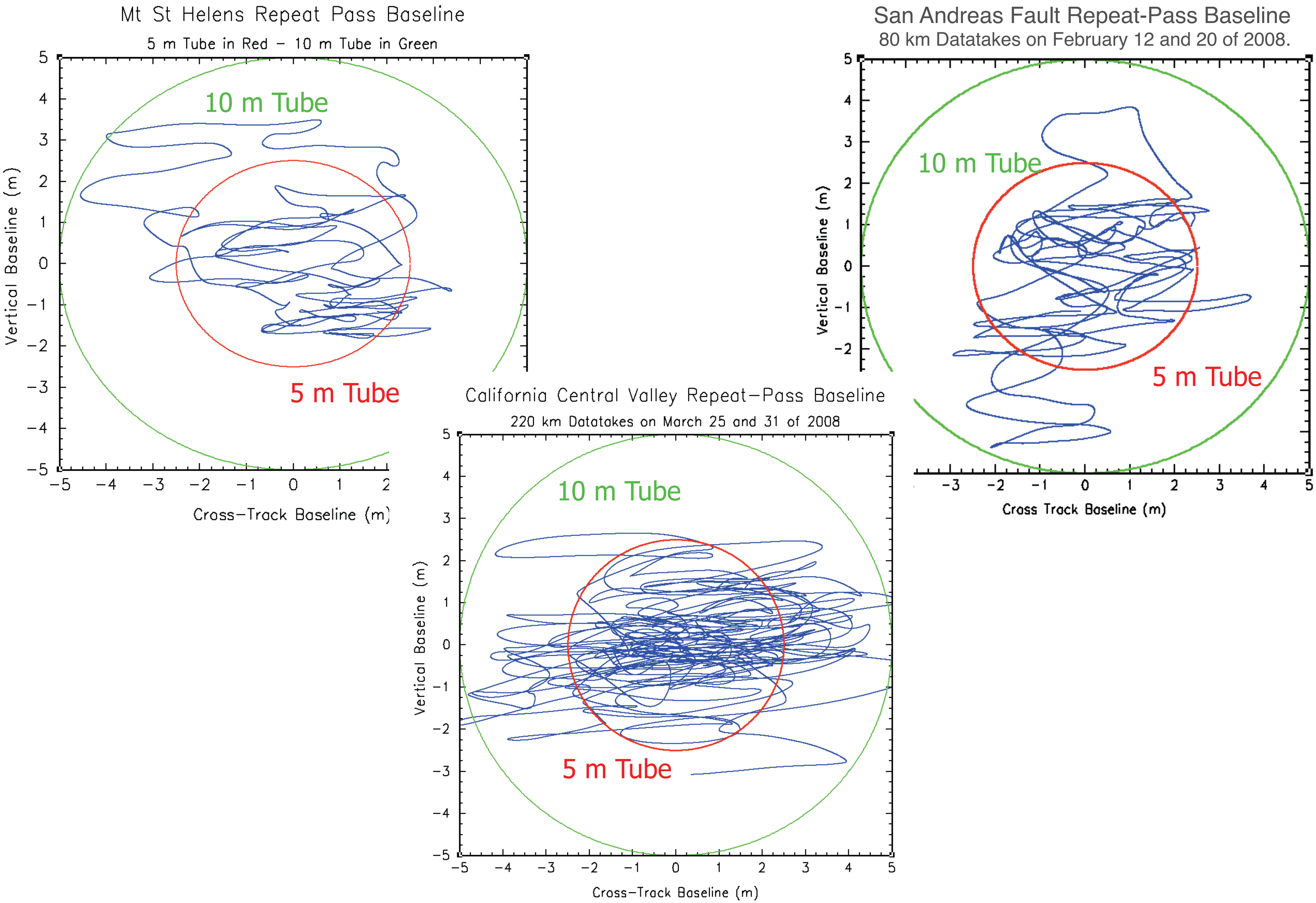
Coming Soon! - UAVSAR on Global Hawk

UAVSAR will fly on Global Hawk in about a year – a real UAV!

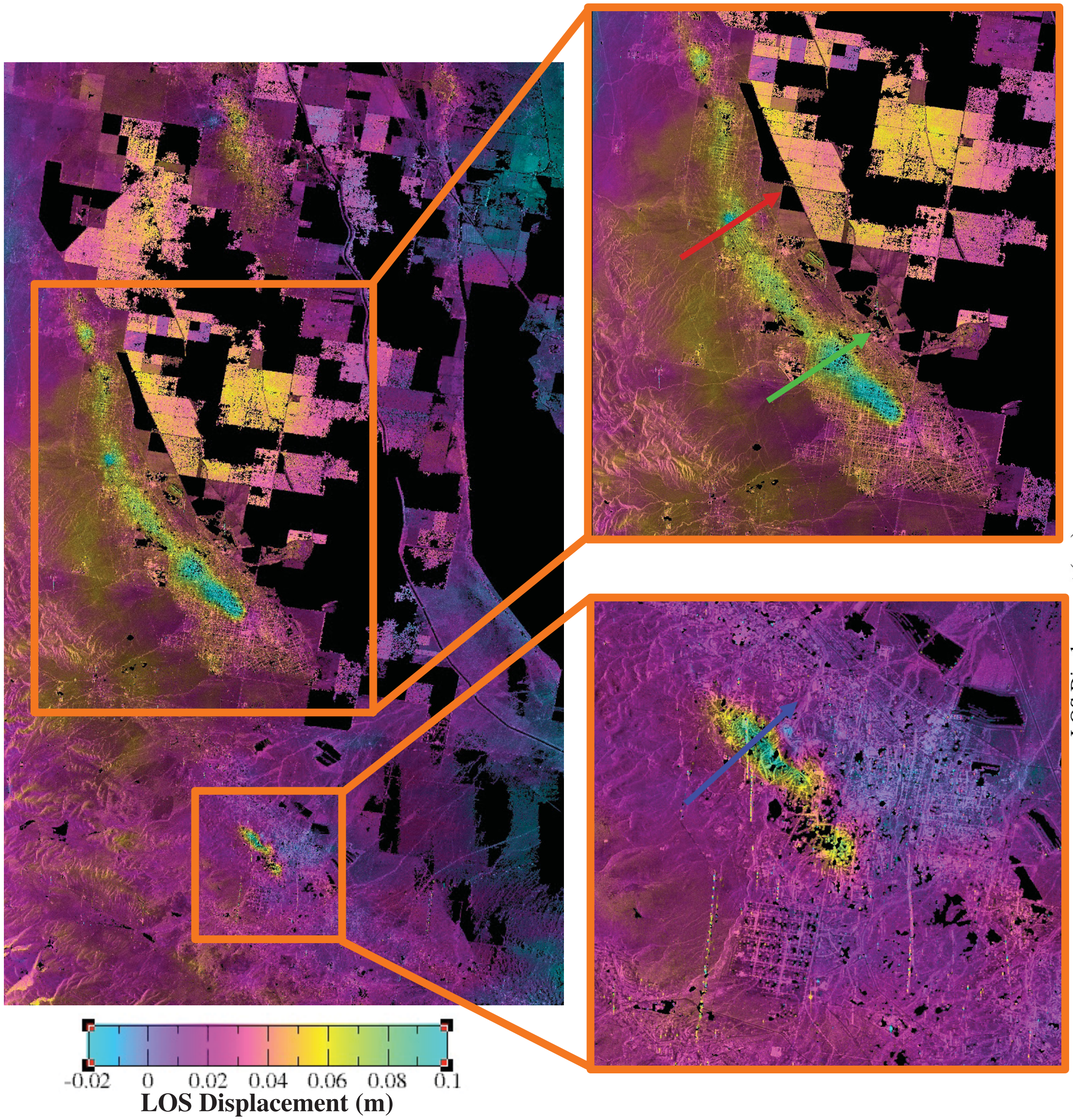
Why can't the pilot fly the plane?



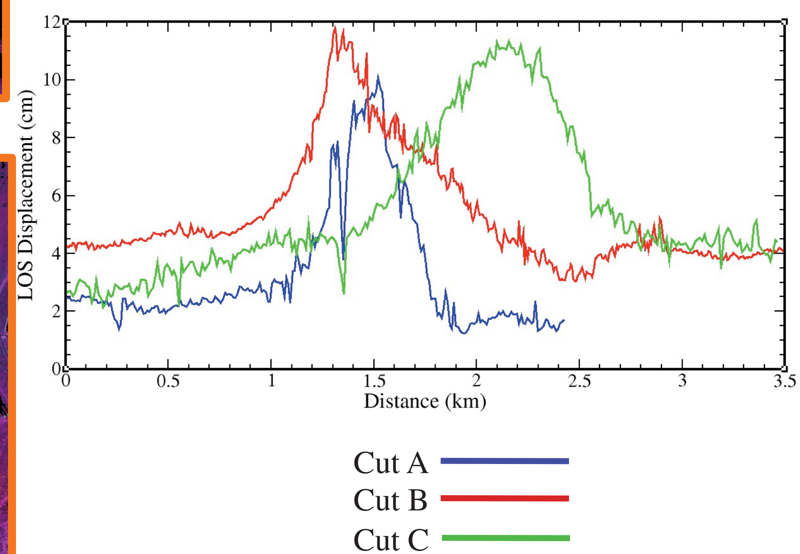
Using the Precision Autopilot



Anthropogenic Induced Surface Deformation



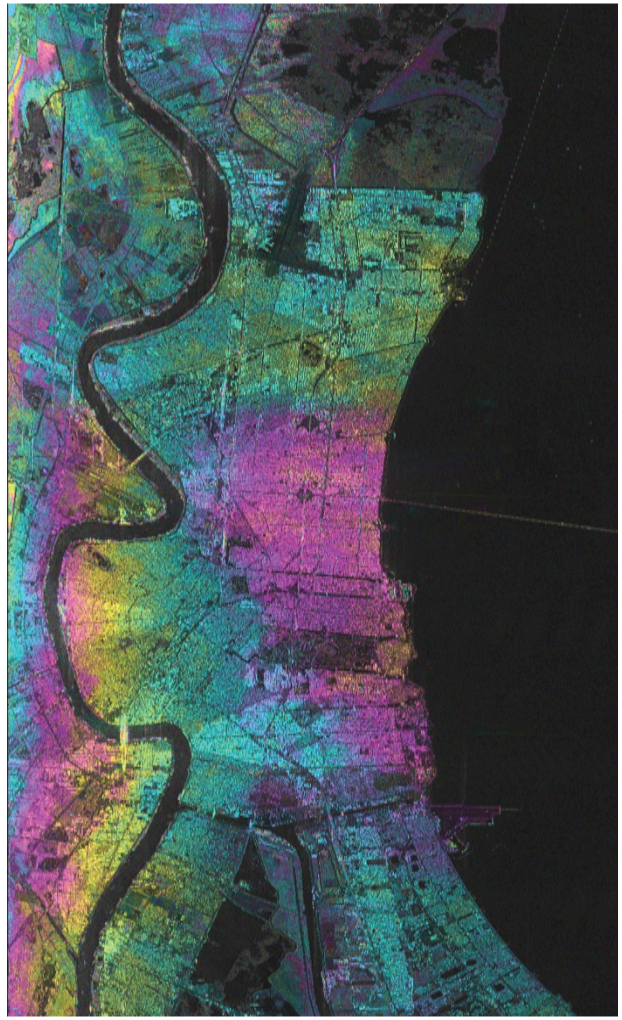
- Approximately 7 cm of surface displacement was observed due to oil pumping in South Belridge oil field, CA over an 80 day period corresponding to a maximal deformation rate of 0.88 mm/day.



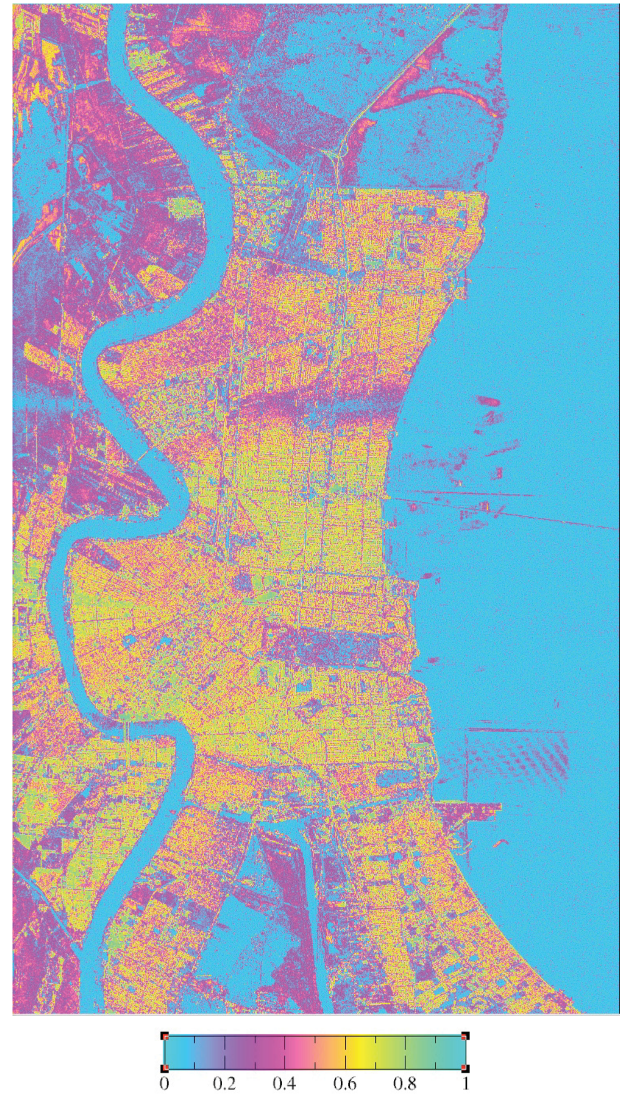
90° Heading Data

Polarimetric Image

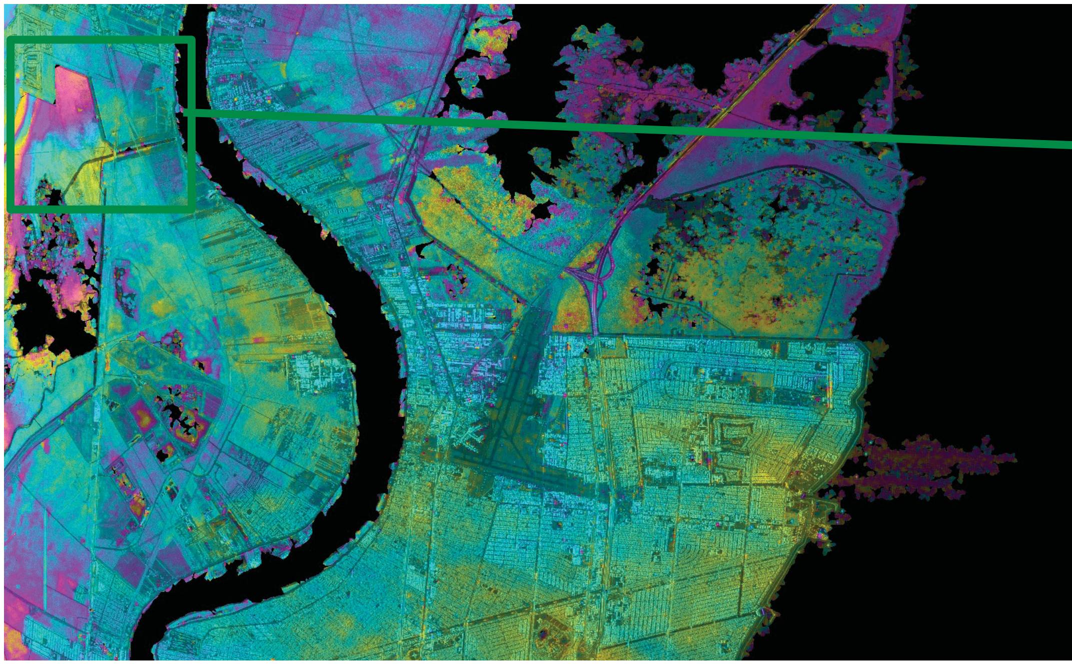
HH Interferogram

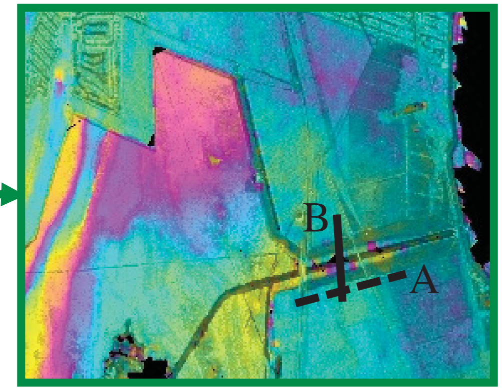


HH Correlation

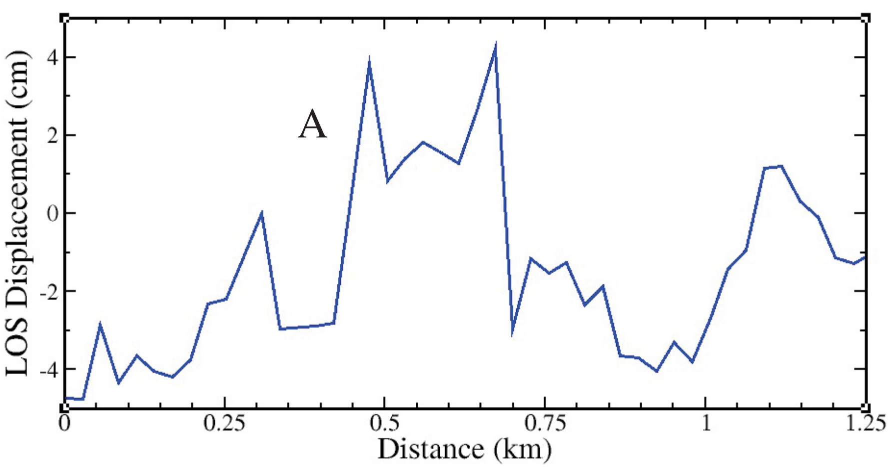


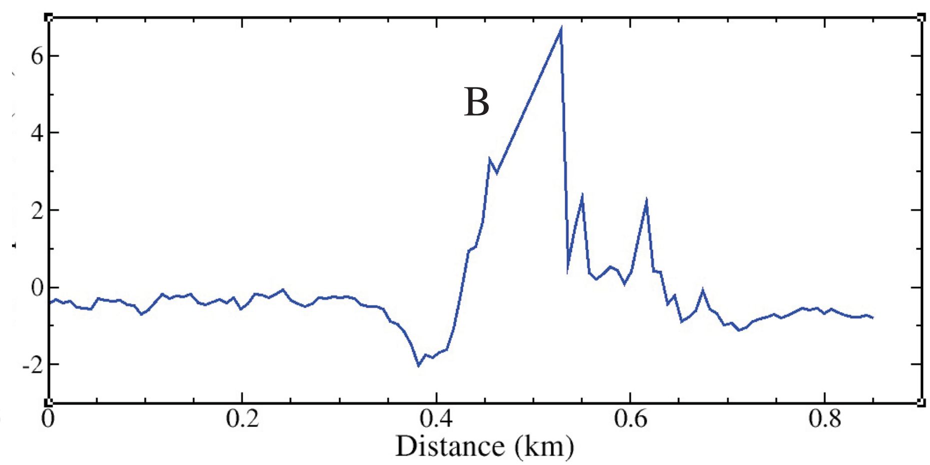
Deformation Along Levee in New Orleans



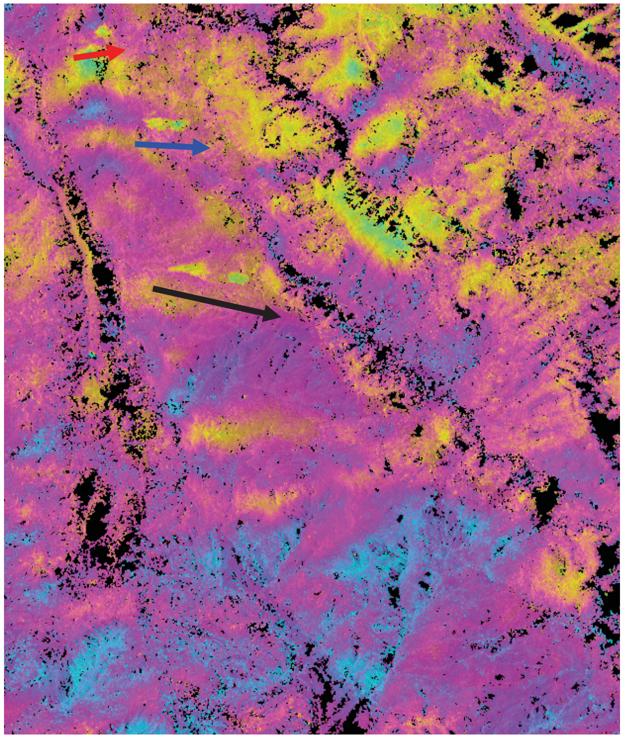


• Localized deformation along levee could be indicative of some structural weakness.

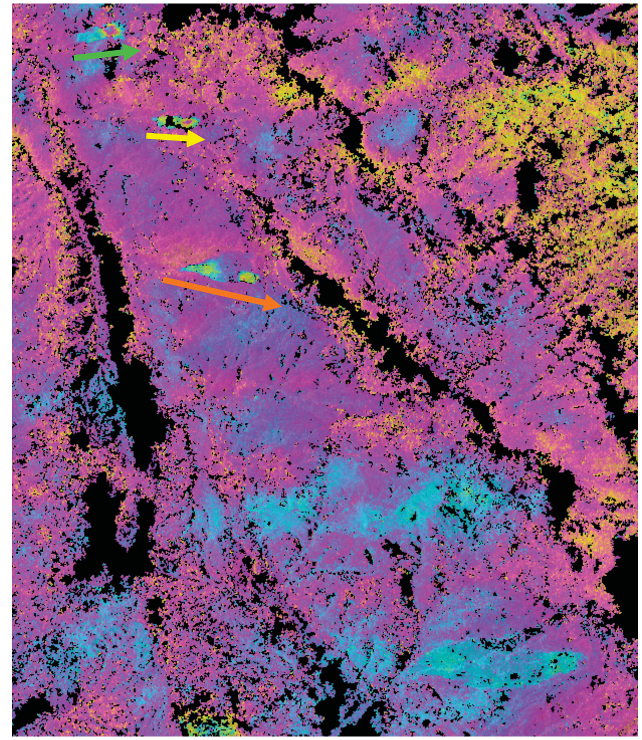


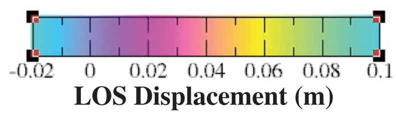


Landslide Motion Detection



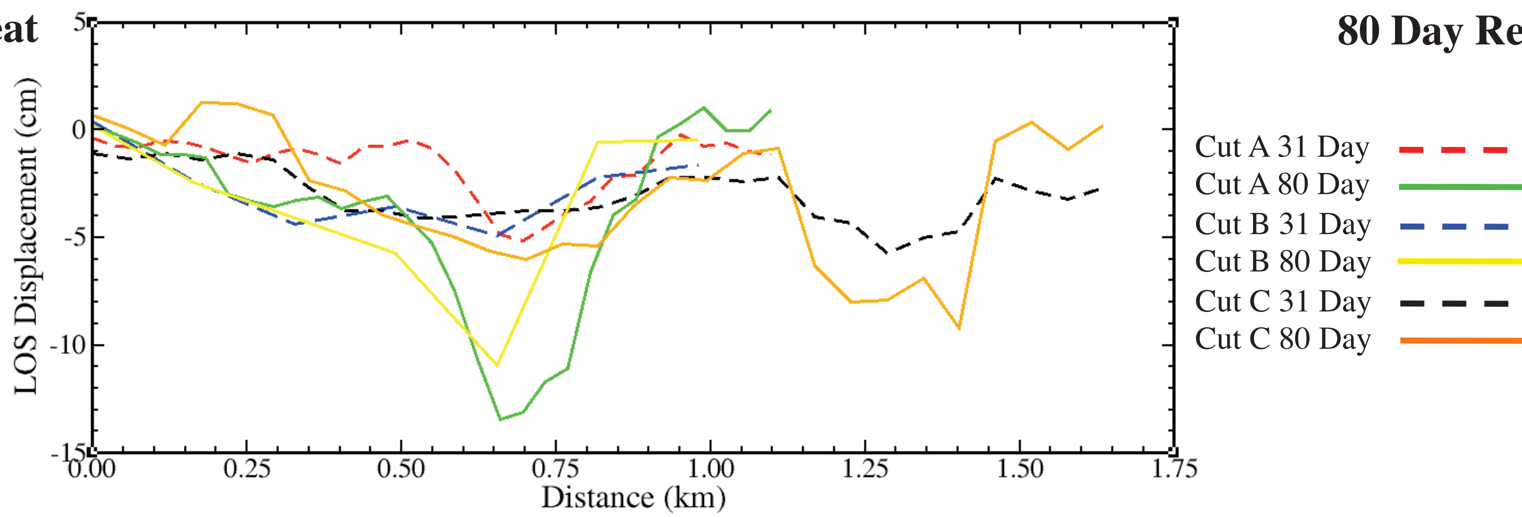
- Creeping landslides detected in 31 and 80 day repeat pass interferograms.
- The amount of deformation increased for the larger pair with the larger temporal baseline indicating continued creep from May to July.



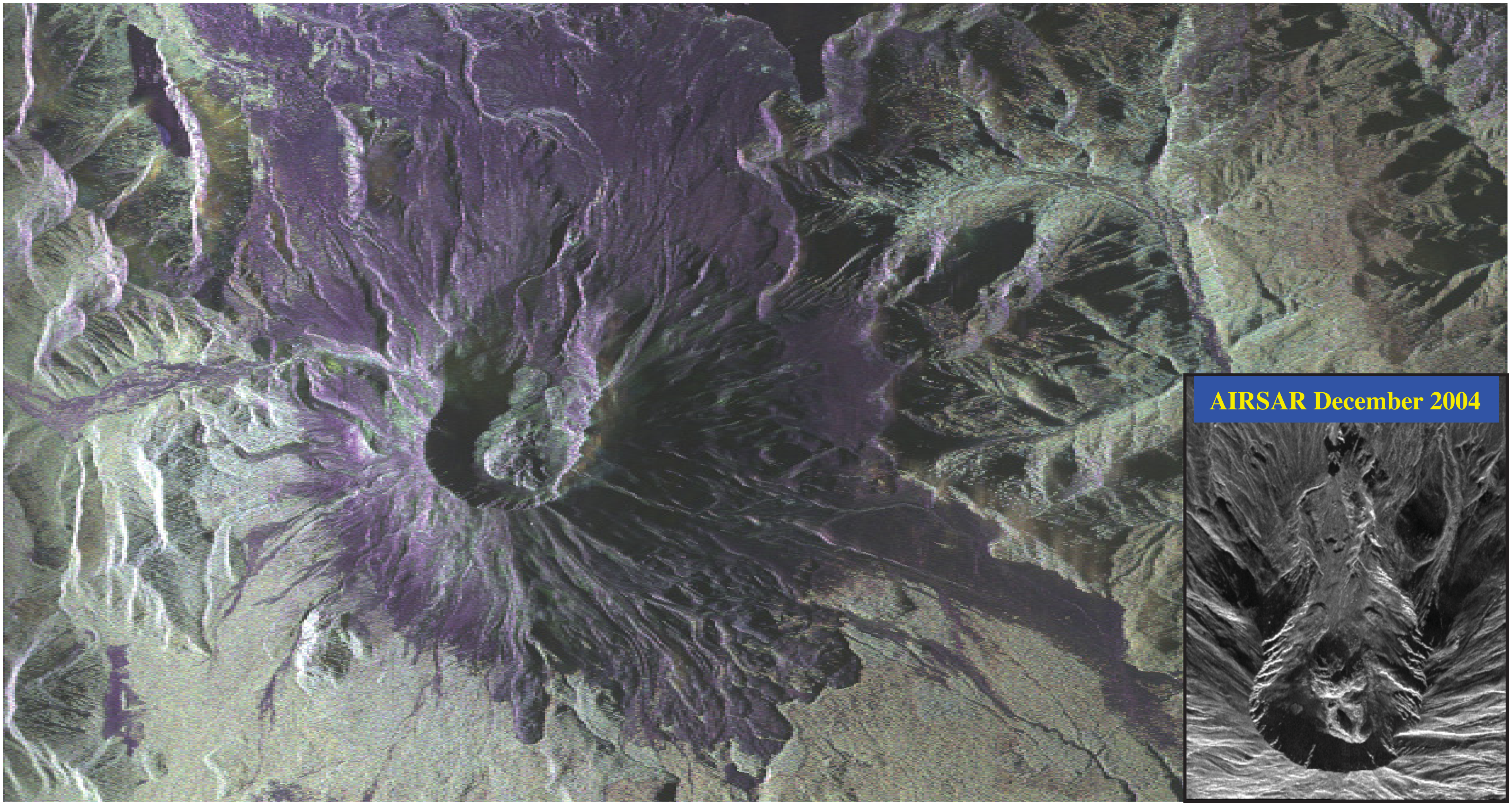


31 Day Repeat

80 Day Repeat

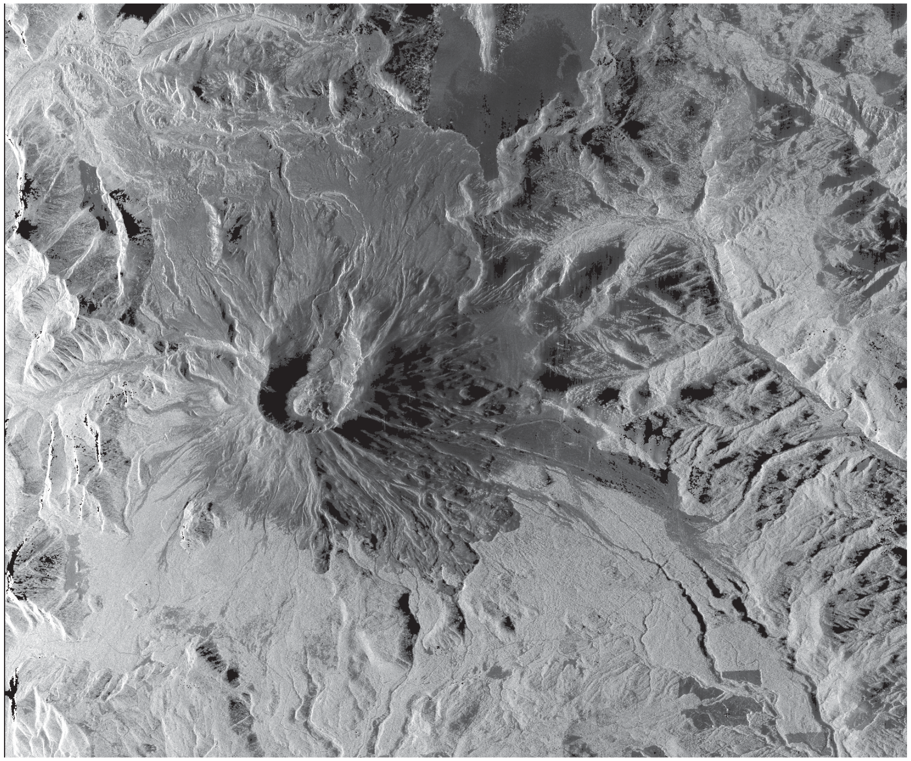


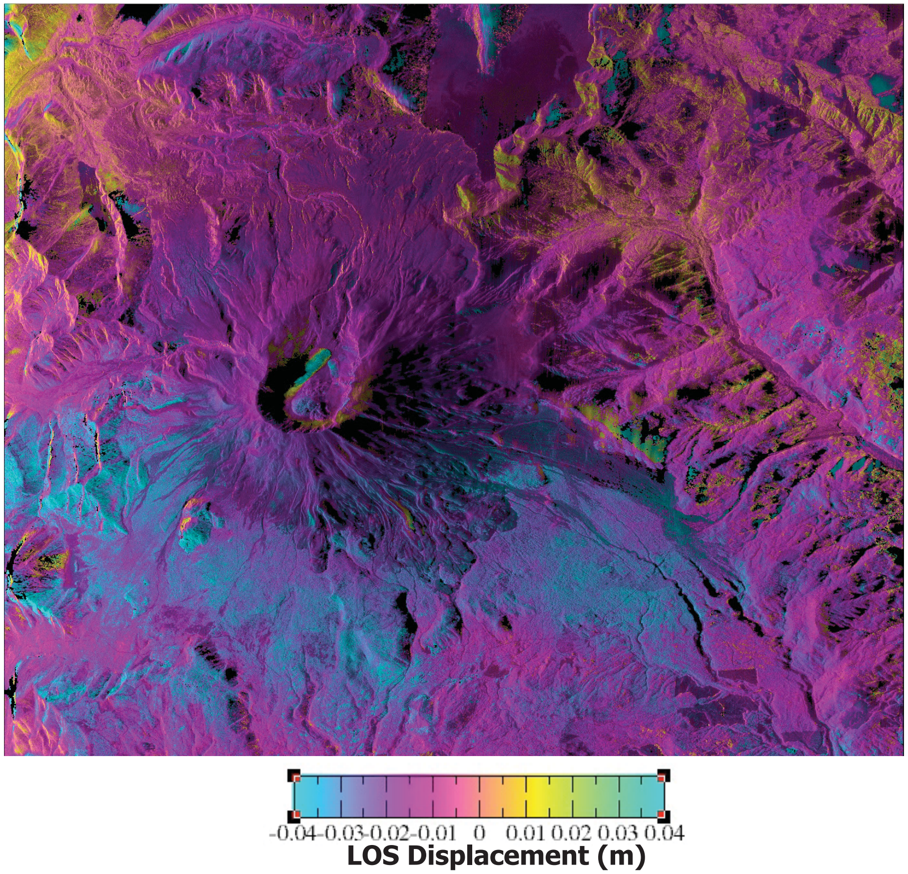
UAVSAR 2008 and AIRSAR 2004



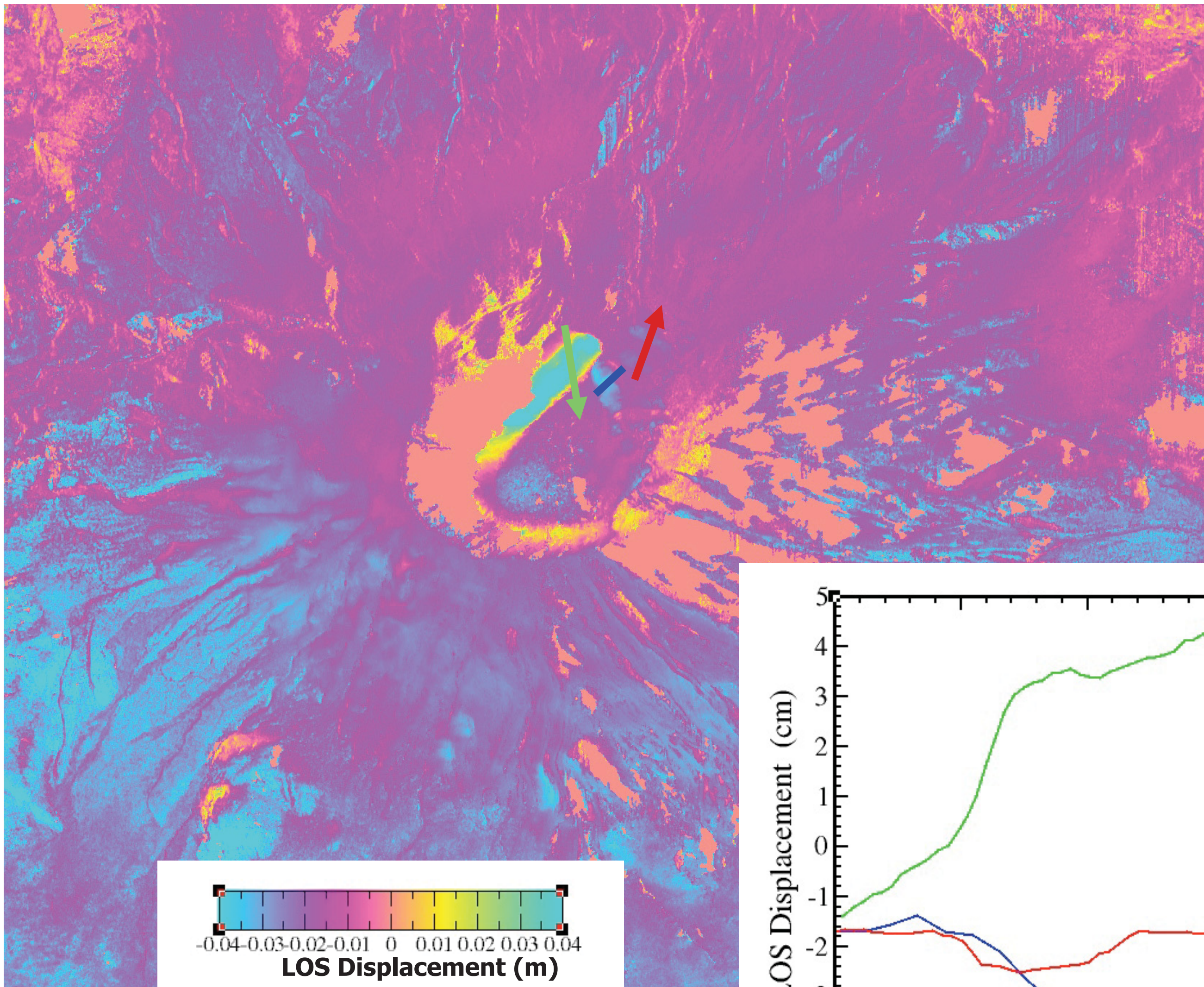
Alpine Glacier Motion on Mt St Helens

- Line-of-sight displacement map from UAVSAR repeat pass interferogram of Mt St Helens.
  - Frozen lake in top middle shows floating logs visible beneath the snow and ice.

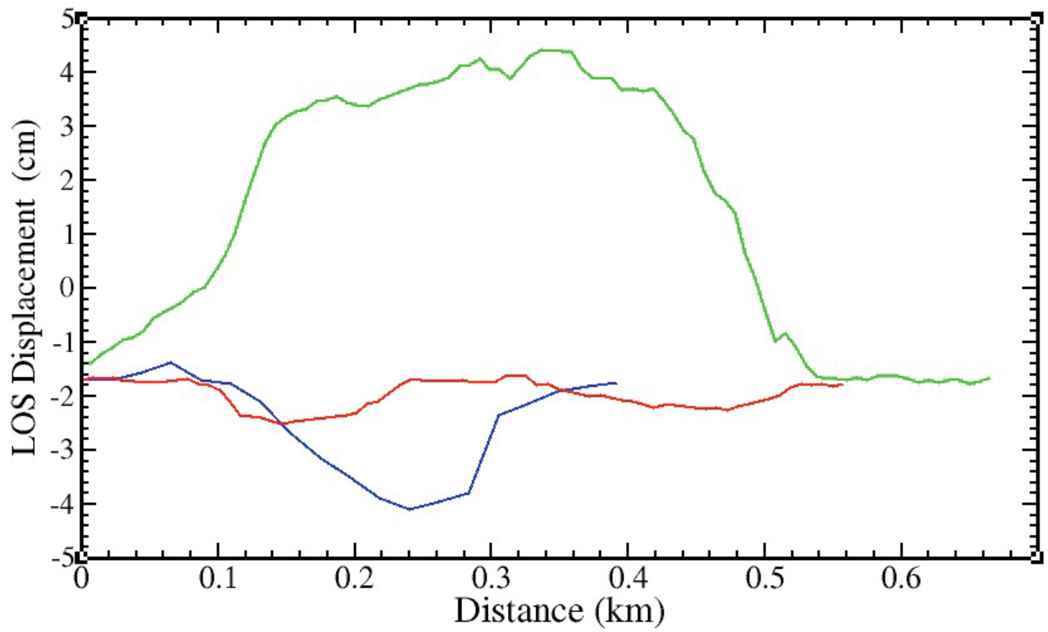




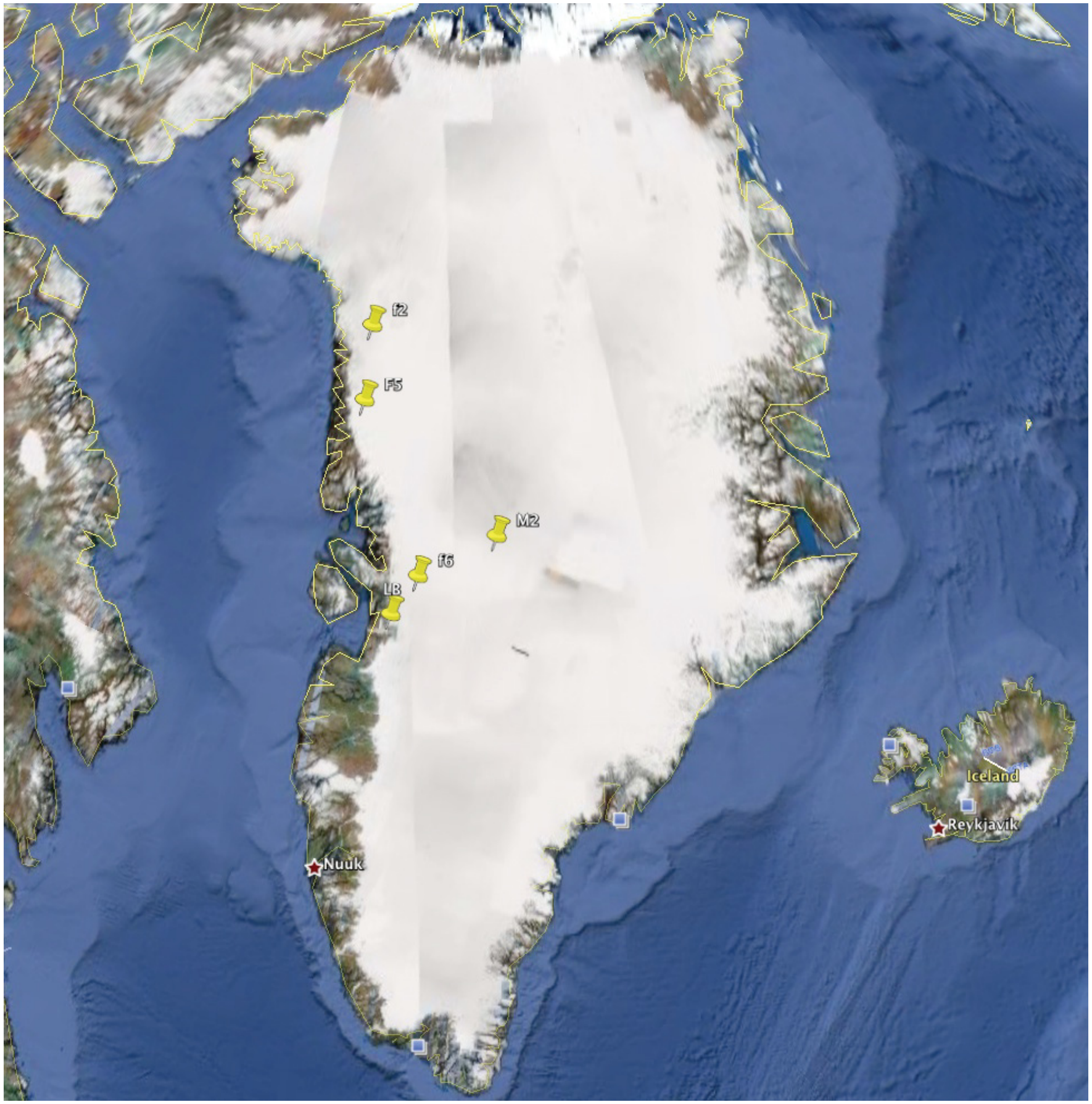
Alpine Glacier Motion on Mt St Helens - II



- The maximal line-of-sight displacement of 5 cm in 0.175 days corresponds to a rate of 28.6 cm/day which is in agreement with values reported by the USGS Cascades Volcano Observatory.



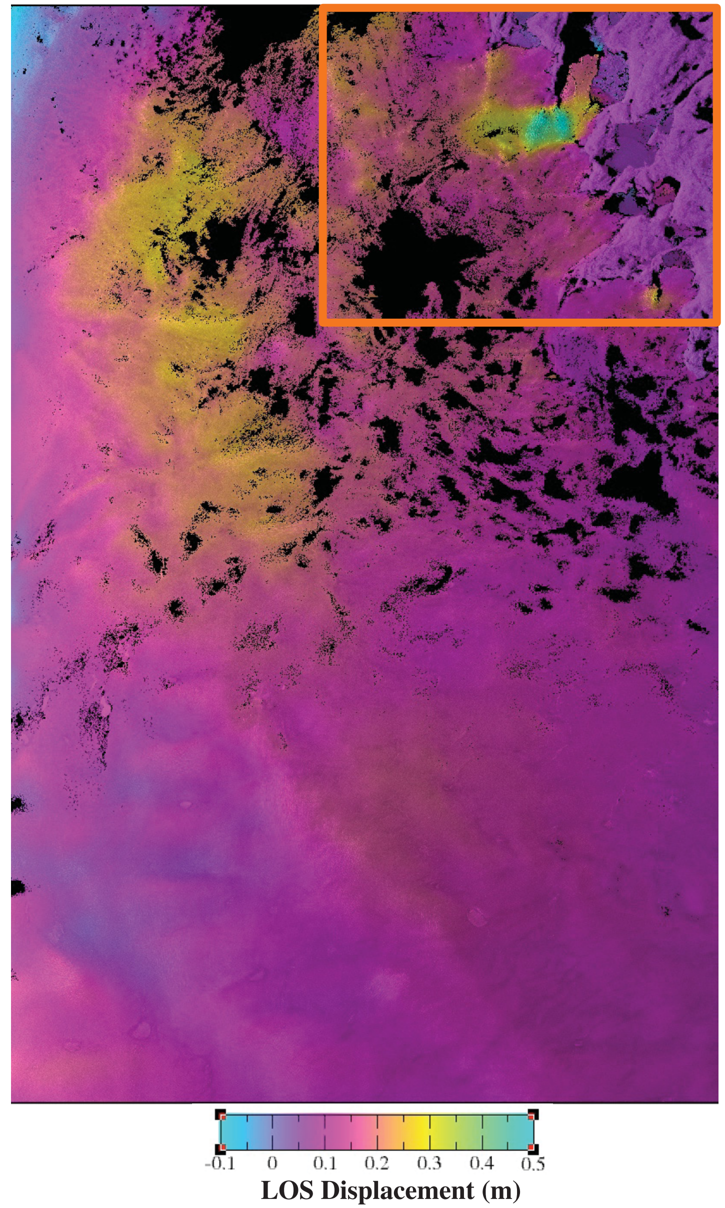
Site Locations



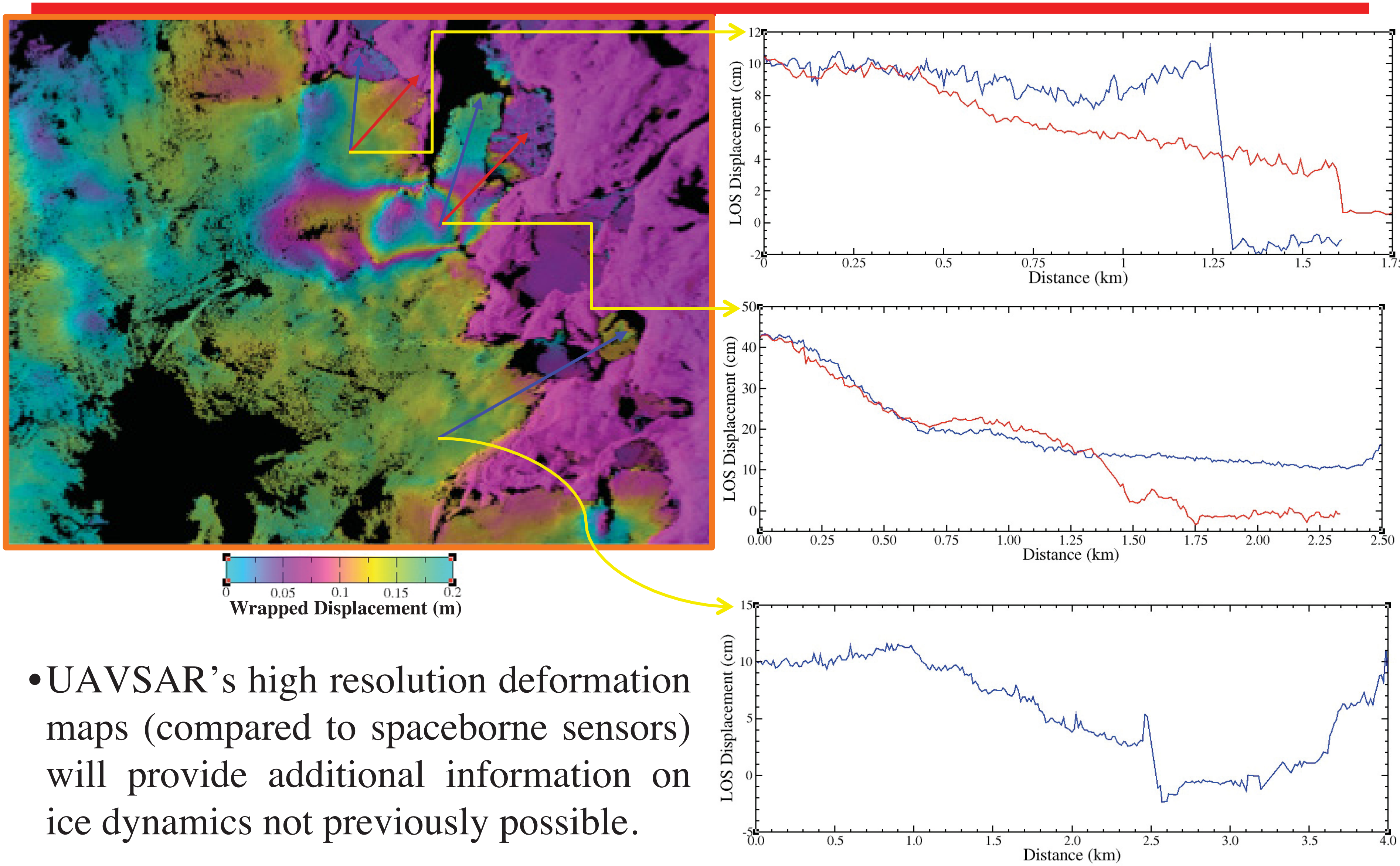
- Data Collected on Three Days:
  - –May 26, 2009
  - –May 27, 2009
  - –June 1, 2009

Ice Sheet Motion in Greenland

Google Earth Image

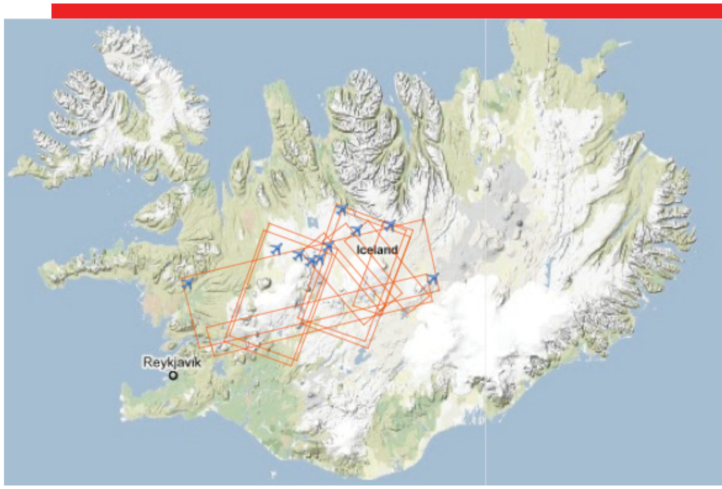


Ice Sheet Motion in Greenland II



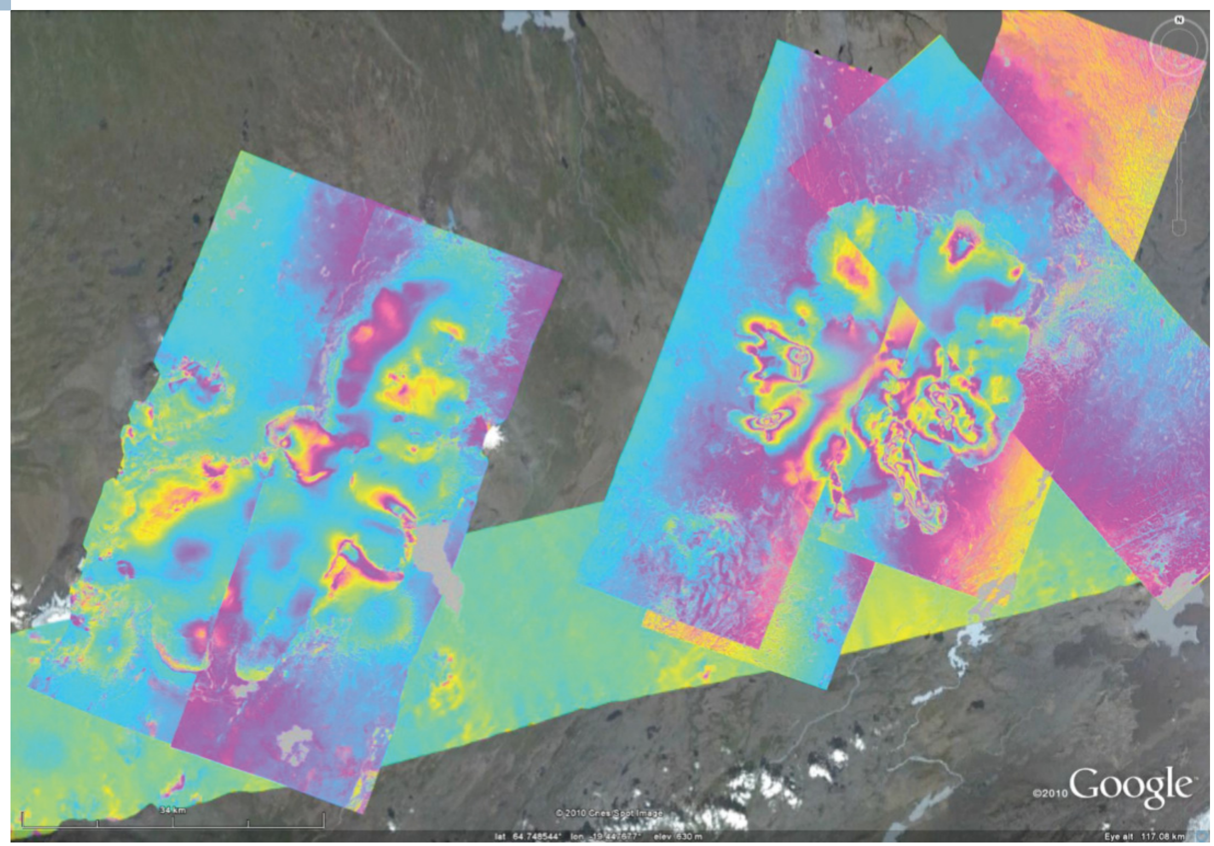
- UAVSAR's high resolution deformation maps (compared to spaceborne sensors) will provide additional information on ice dynamics not previously possible.

Mapping Glacier Motion in Iceland



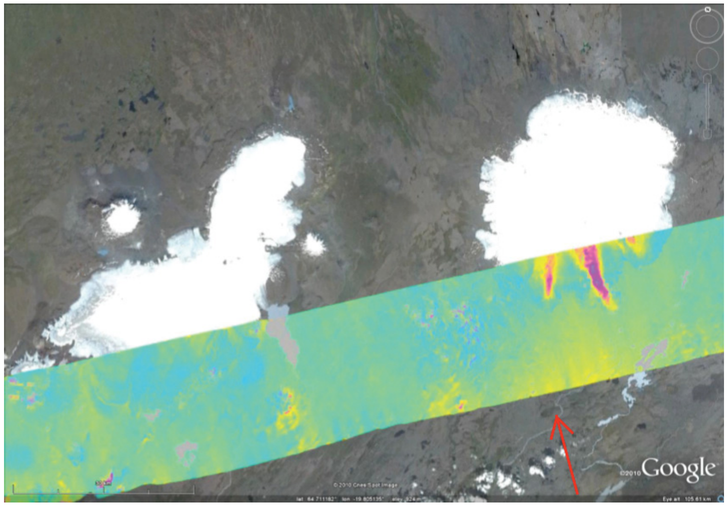
- Hofsjkull and Langsjokull glaciers were mapped on multiple days and on multiple headings in order to gain a better understanding of the ice dynamics.

- Sampling of the deformation images generated from the Iceland UAVSAR data.
- Data will allow to solve for the three dimensional deformation.



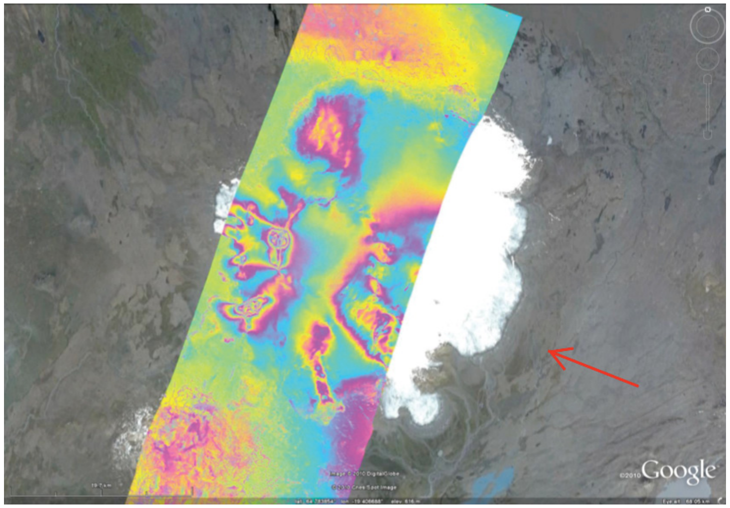
Expanded Deformation Products - Hofsjkull

- Different headings and different time intervals provide additional detail of the surface deformation.

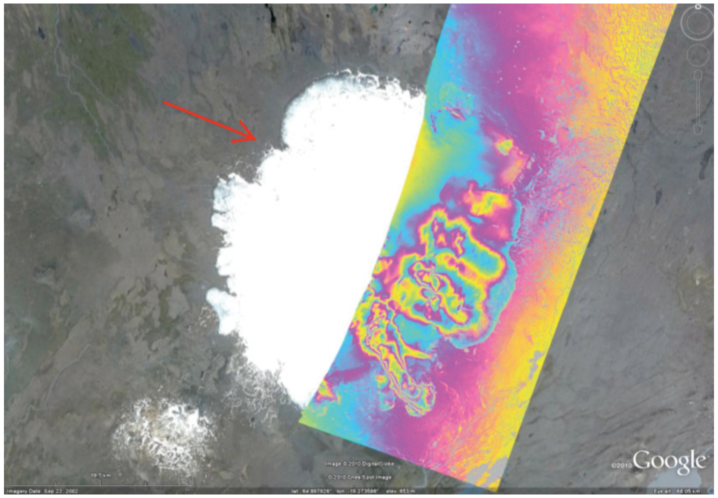


- 4 hour repeat time
- June 10, 2009

- 26 hour repeat time
- June 12-13, 2009

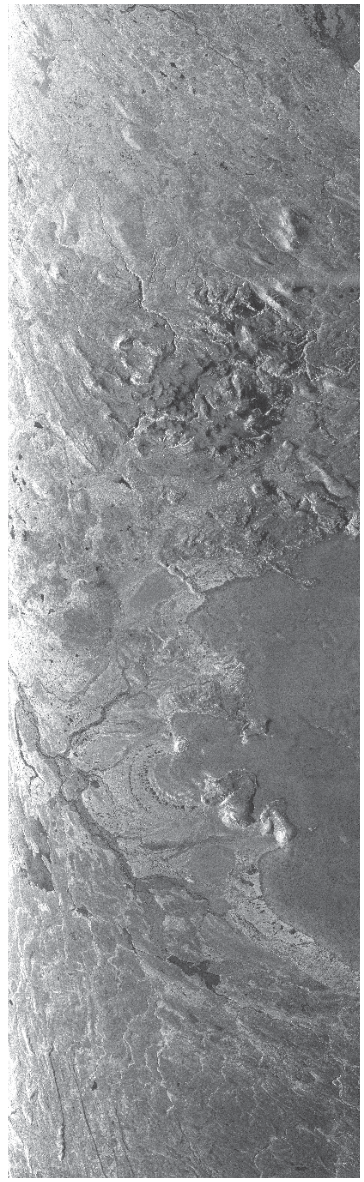


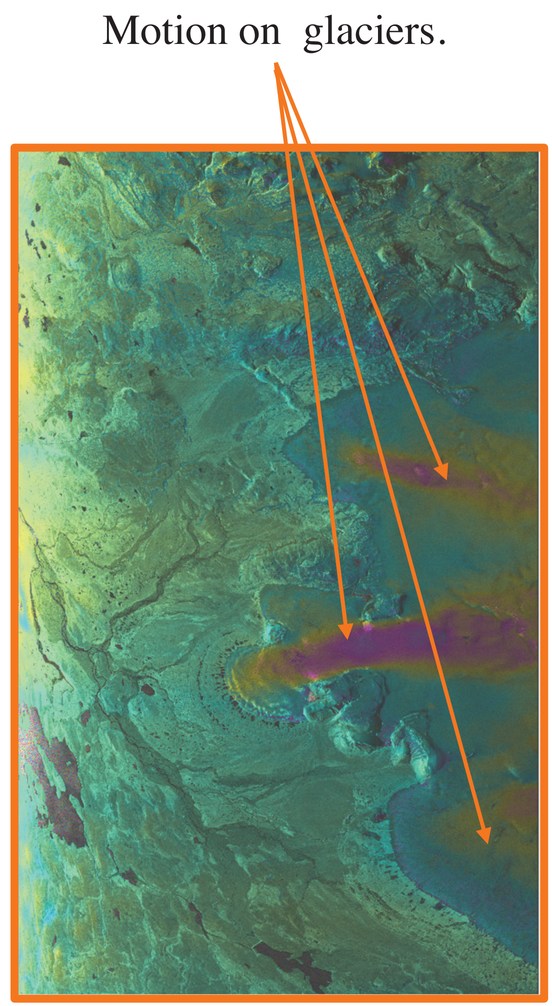
- 26 hour repeat time
- June 12-13, 2009



Iceland Interferogram - 4 Hour Repeat

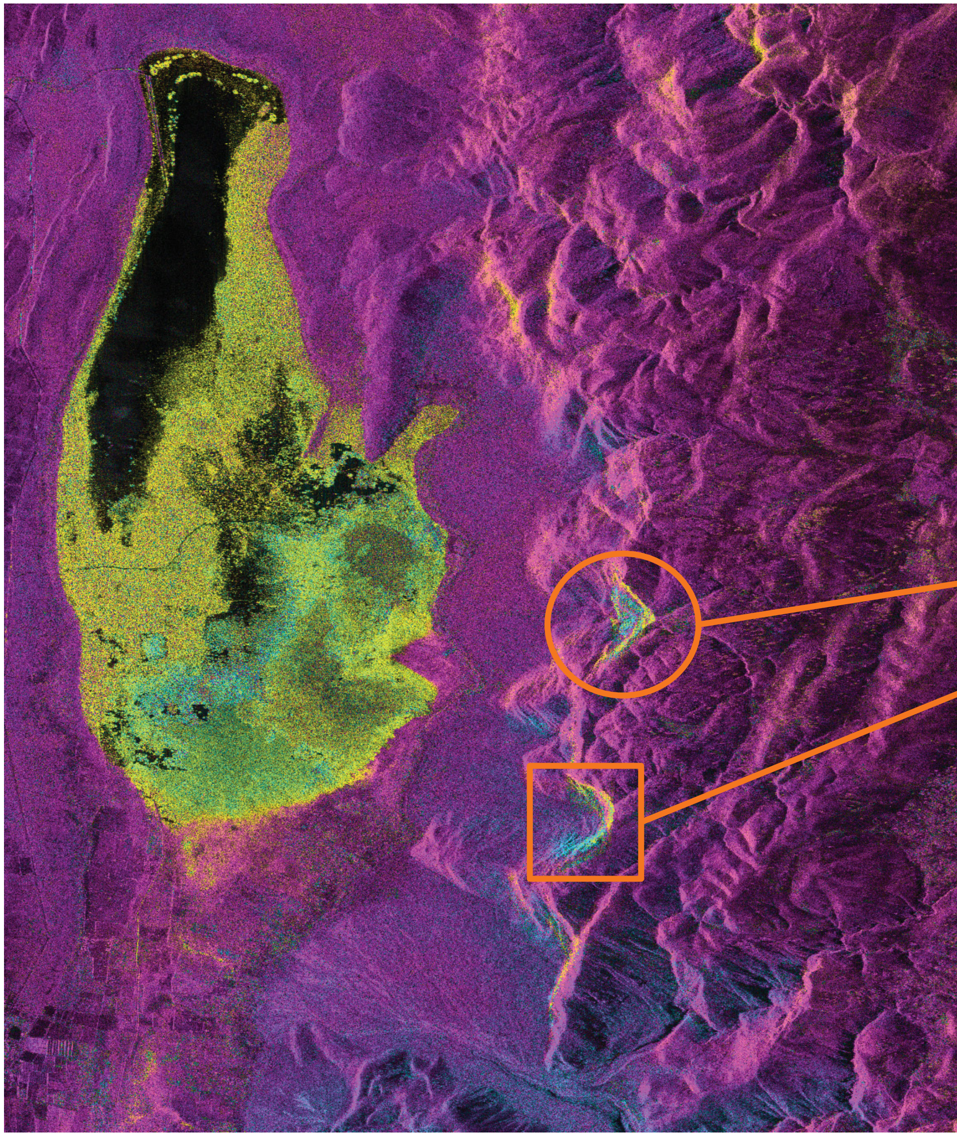
- 4 hour repeat pass deformation map.

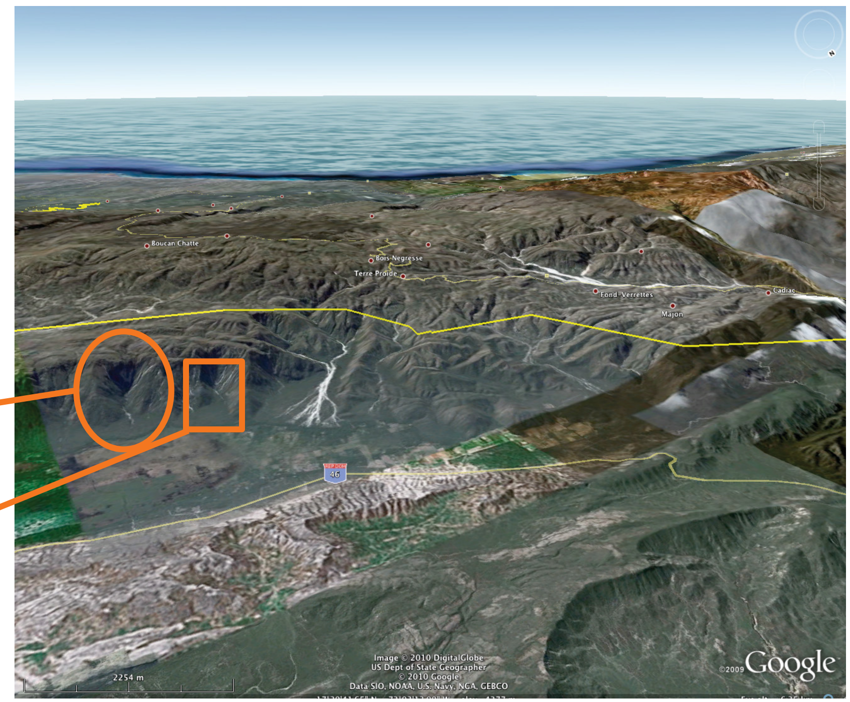




Potential Landslides in Haiti

Data collected after the Haiti earthquake has detected possible slides and Coastal area deformation.

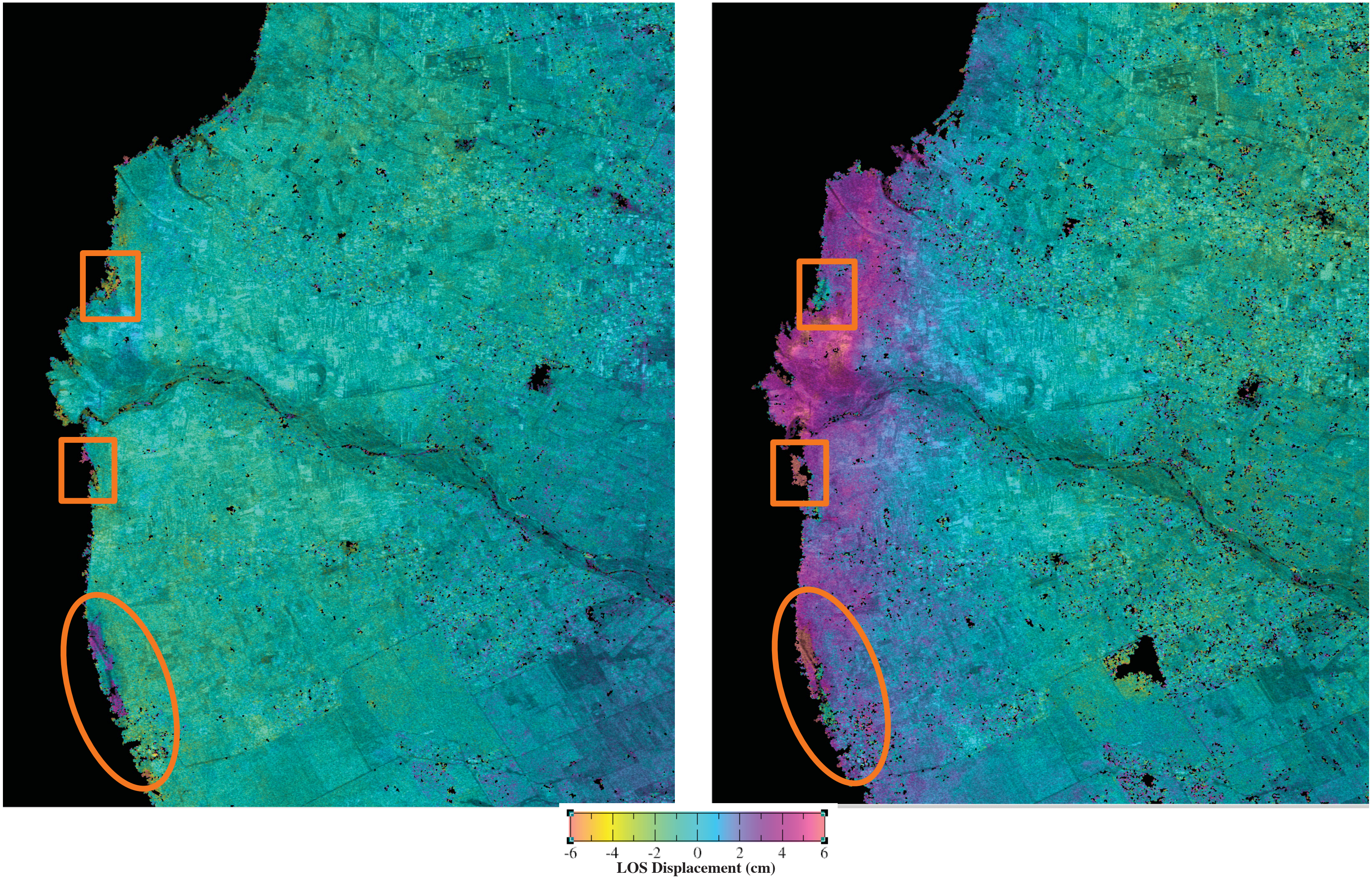




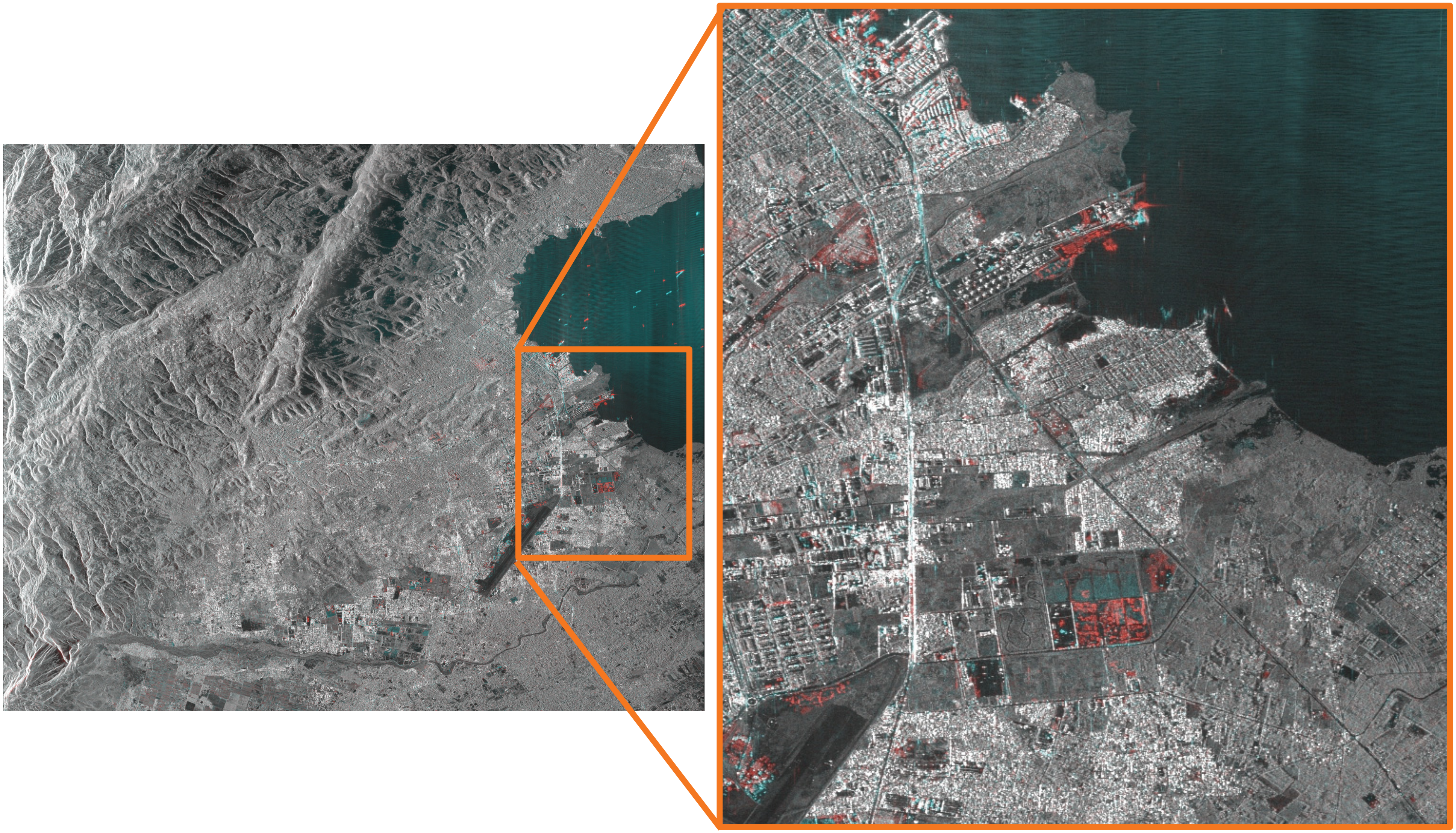
Potential landslide areas detected by UAVSAR. Data is approximately 2.5 m range 3.6 m azimuth resolution.

UAVSAR Post-Quake Coastal Deformation

6-Day Repeat **16-Day Repeat**

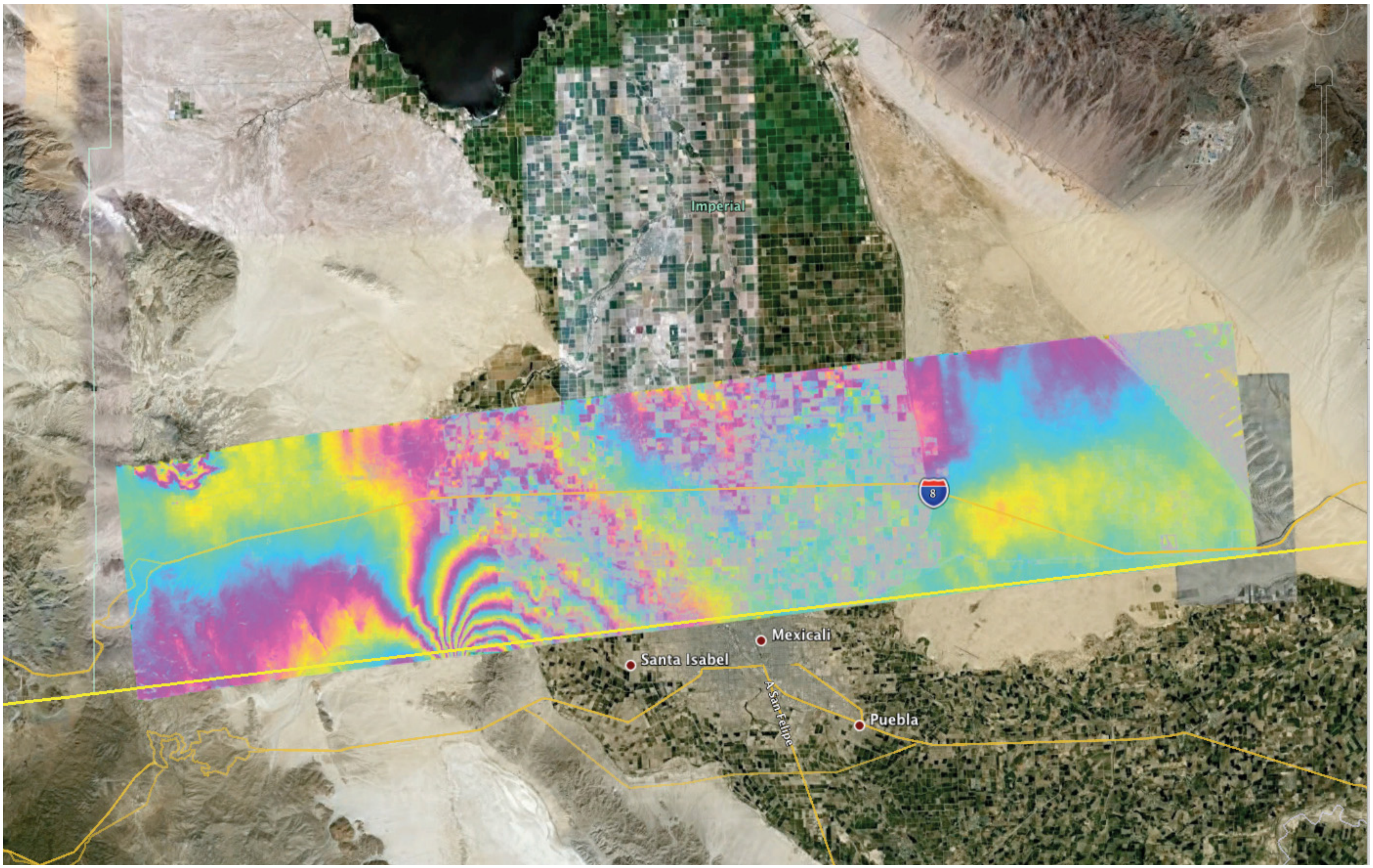


Incoherent Change Detection

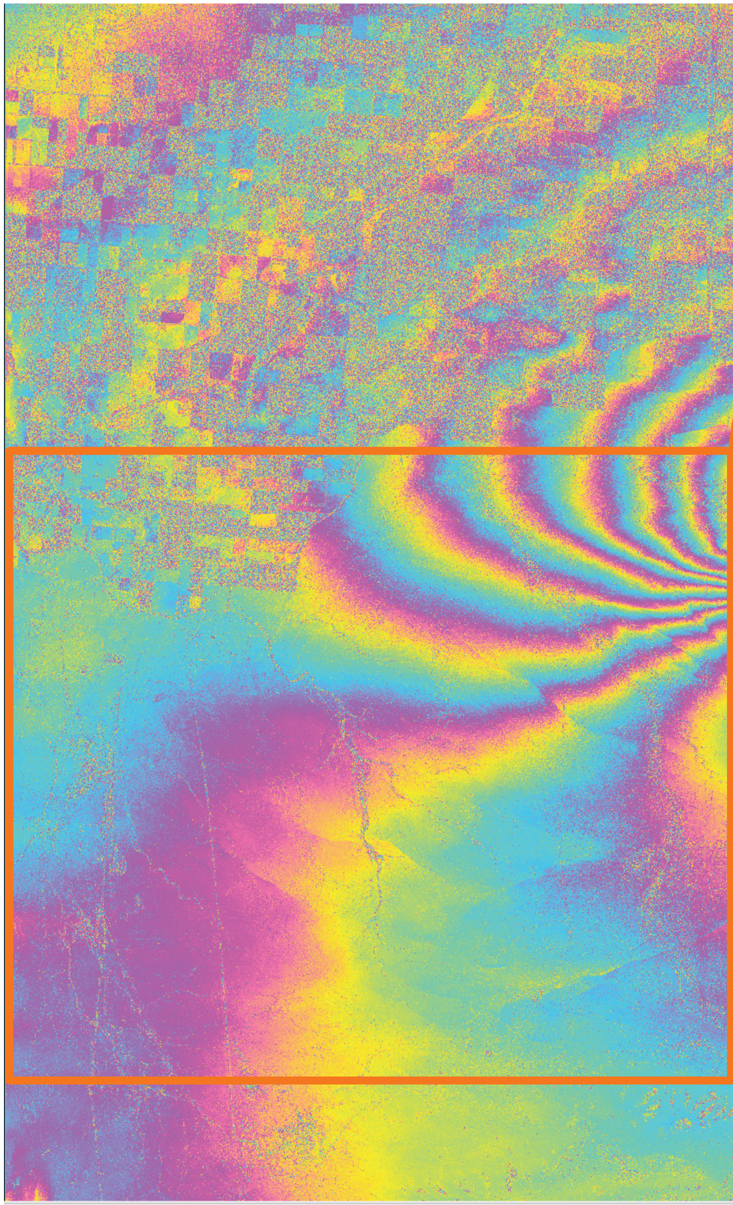


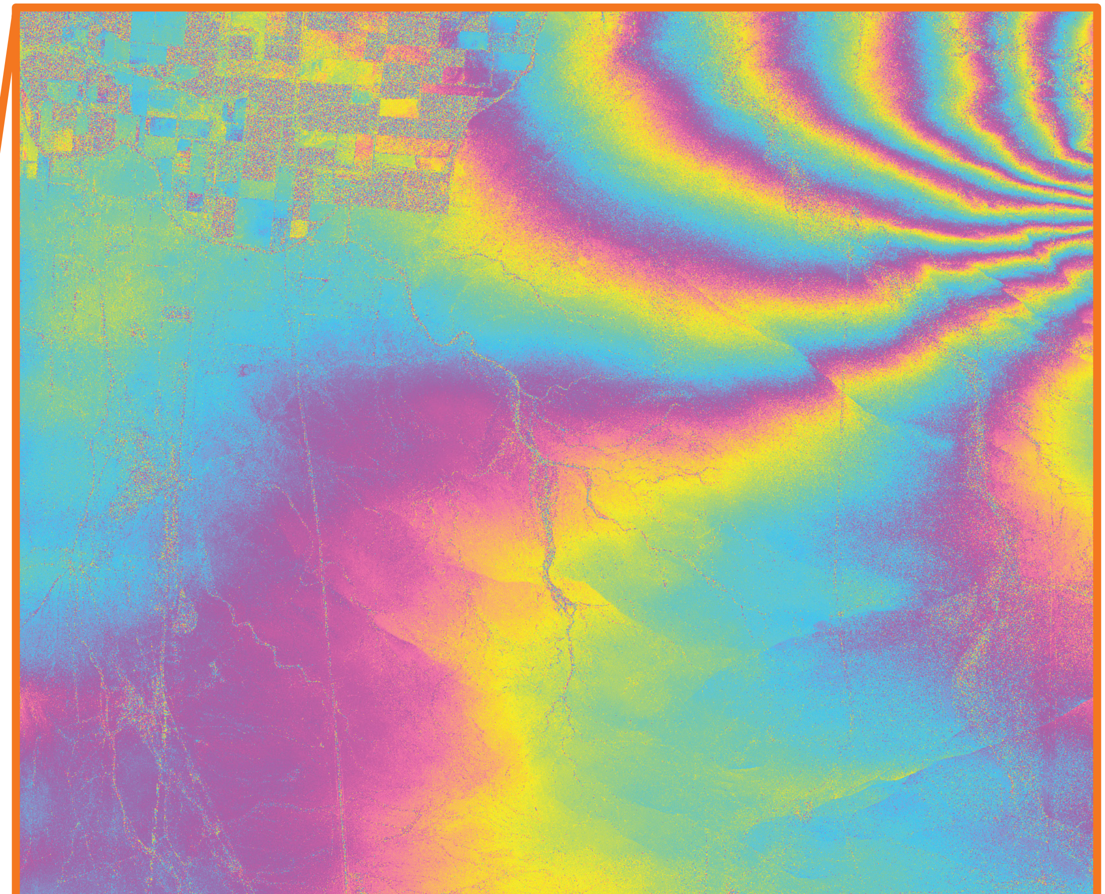
April 4, 2010 M 7.2 Baja California Earthquake

- First earthquake deformation captured by the UAVSAR system using data acquired on October 21, 2009 and April 13, 2010.



Expanded View of Earthquake





- Subtle faulting is visible in the high resolution six month temporal (174 days) baseline L-band UAVSAR interferogram.

Fault Slip Continued After April

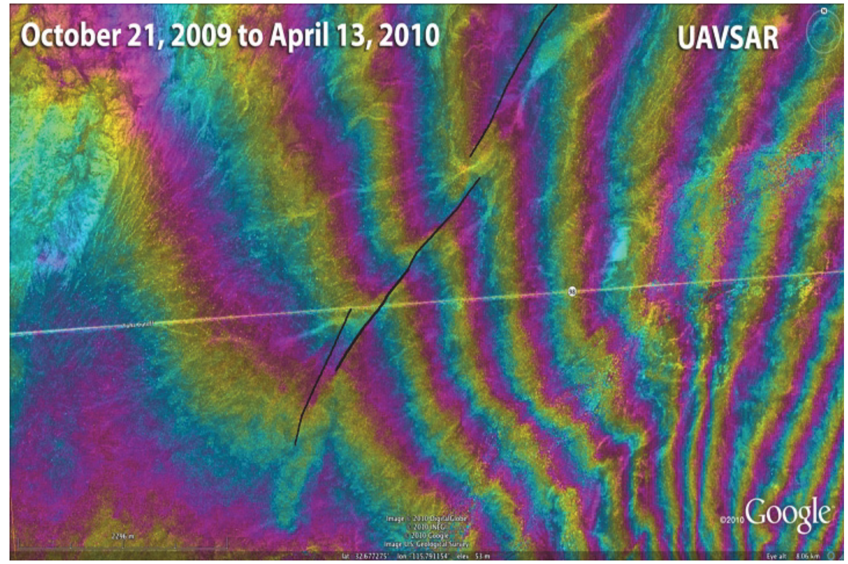
- Numerous small fault offsets 0.5–4.5 cm on faults trending northwest and northeast in Yuha desert

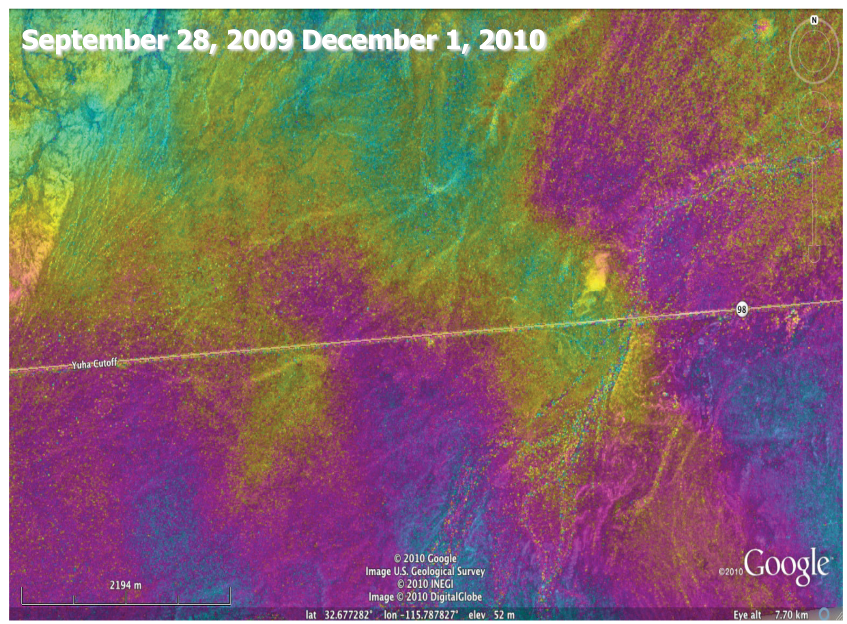
- Yuha Fault slipped at time of main earthquake and afterwards, but motion mostly stopped after July.

- Fourth UAVSAR flight after earthquake shows no additional fault slip in Yuha Desert

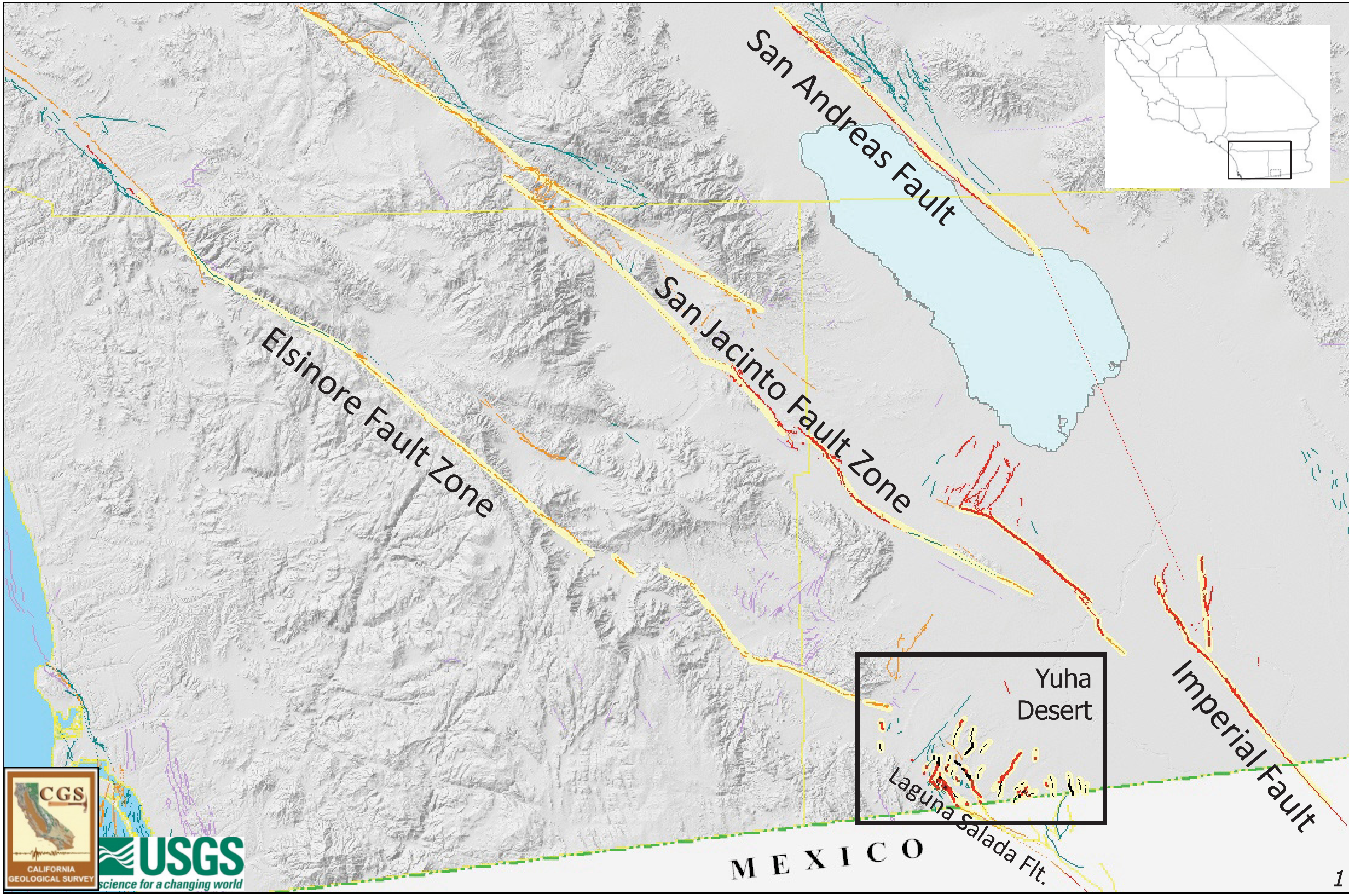
Image Resolution ~7 m, 5 cm contours

Newly Mapped Yuha Fault

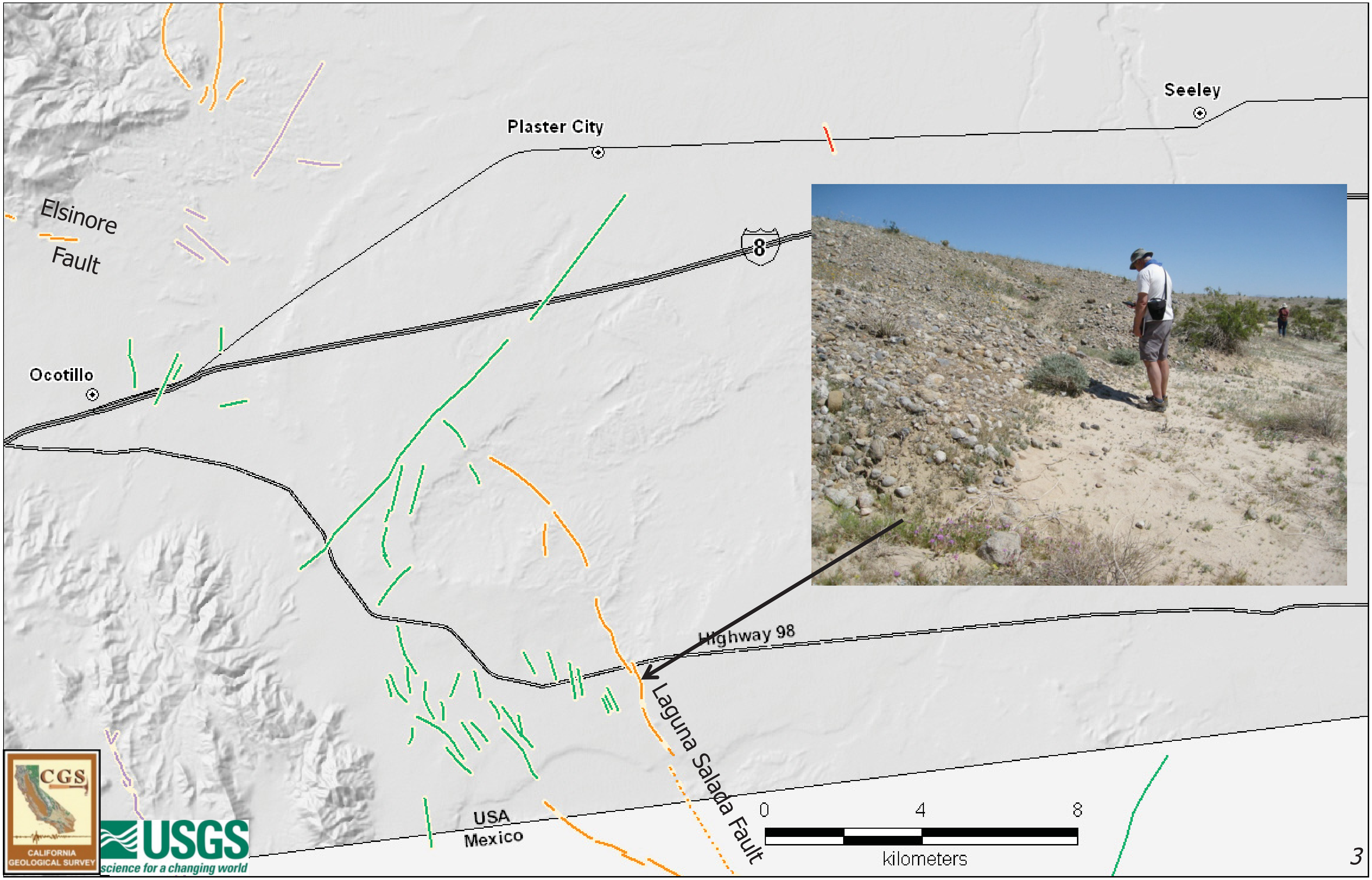




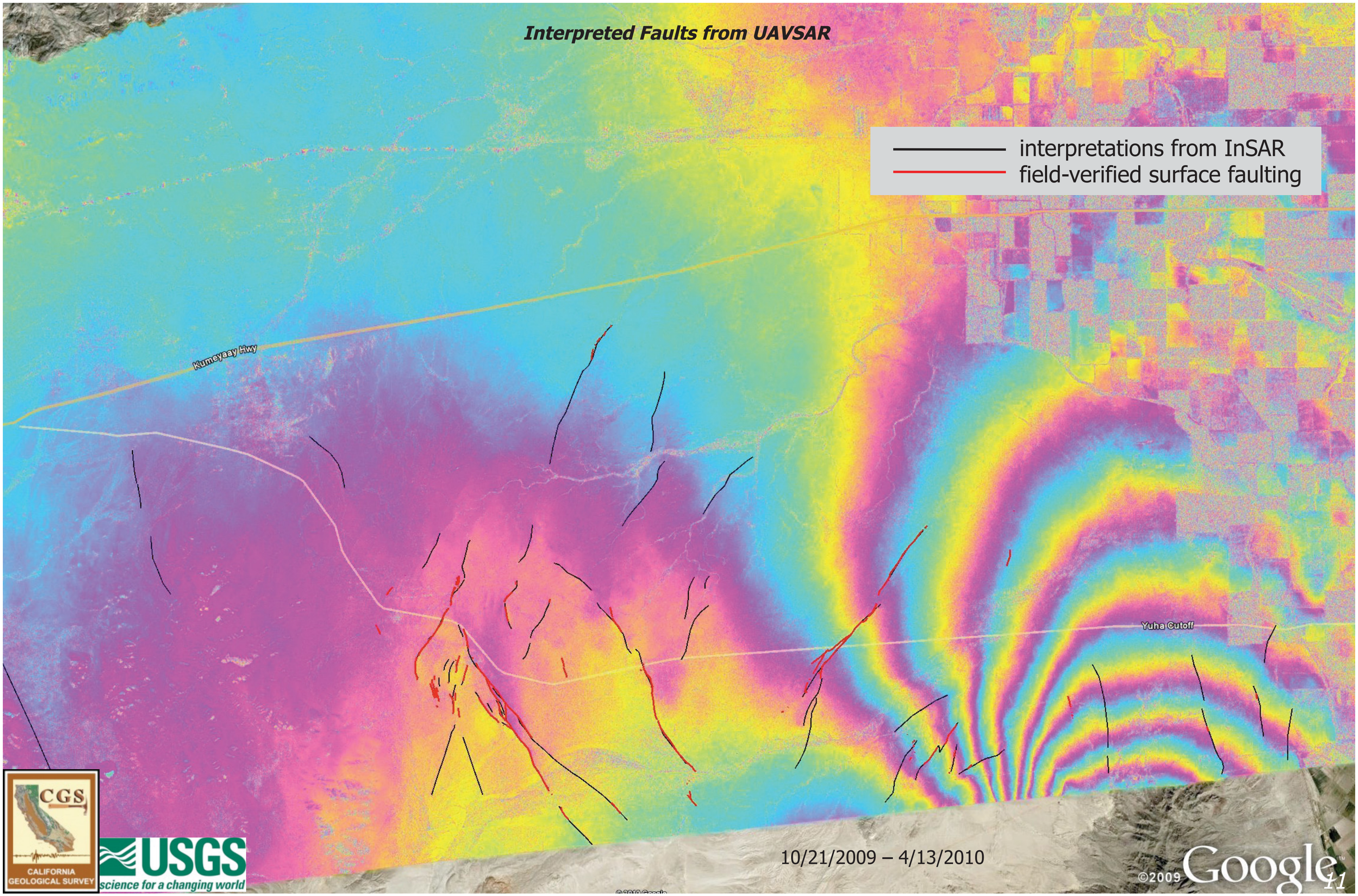
Context of the Yuha Desert Faults



Previously Mapped Faults in the Yuha Desert



Interferogram - 10/21/2009 – 4/13/2010



Conclusions

- UAVSAR's precision autopilot and electronic steering have allowed for the reliable collection of airborne repeat pass radar interferometric data for deformation mapping.

- Deformation maps from temporal scales ranging from hours to months over a variety of signals of geophysical interest illustrate the utility of UAVSAR airborne repeat pass interferometry to these studies.

For more info see: http://uavsar.jpl.nasa.gov